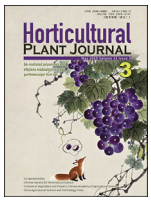
May 2025. Horticultural Plant Journal, 11 (3): 1231–1247

Horticultural Plant Journal

Available online at www.sciencedirect.com
The journal's homepage: http://www.keaipublishing.com/en/journals/horticultural-plant-journal



Research Paper

Preharvest applications of monopotassium phosphate to improve fruit quality and volatilome composition in cold-stored cherry tomato

Miriam Distefano [a], *Fabrizio Cincotta* [b], *Francesco Giuffrida* [c], *Concetta Condurso* [b], *Antonella Verzera* [b], *Cherubino Leonardi* [c], *and Rosario Paolo Mauro* [c,*]

[a] *CNR – Consiglio Nazionale delle Ricerche IBE – Istituto per la BioEconomia, Catania 95126, Italy*
[b] *Dipartimento di Scienze Veterinarie, Università degli Studi di Messina, Polo Universitario dell'Annunziata, Messina 98168, Italy*
[c] *Dipartimento di Agricoltura, Alimentazione e Ambiente (Di3A), Università degli Studi di Catania, Catania 95123, Italy*

Received 2 September 2023; Accepted 25 December 2023; Available online 16 September 2024

A B S T R A C T

The experiment addressed the effects of preharvest KH_2PO_4 foliar spraying (20 mmol · L^{-1}) on fruit quality and composition (including volatile organic compounds, VOCs) of cherry tomatoes ('Caravaggio', 'Sugarland' and 'Top Stellina') after 0 (S_0), 7 (S_7) and 14 days (S_{14}) of storage at 8.0 °C. On the average of the 3 genotypes, the KH_2PO_4 treatment improved fruit pressure firmness, total soluble solids (TSS), titratable acidity (TA), total phenols and carotenoids concentrations, along with the fruits' antioxidant capacity (by up to 17% for FRAP assay). Within the S_7–S_{14} period, control fruits showed the highest reductions in TSS, TSS/TA ratio and total carotenoids (−17, −12 and −45, respectively), whereas treated fruits proved the strongest increase in DPPH (+12%). Sixteen out of 32 VOCs were promoted following KH_2PO_4 application, including the aldehydes hexanal, (E)-2-hexenal and (Z)-3-hexenal and the apocarotenoids (E)-citral, (E)-β-ionone, geranylacetone and 6-methyl-5-hepten-2-one. Proceeding from S_0 to S_{14}, several VOCs decreased more strongly in control fruits, as for hexanal (−48%↘) and total aldehydes (−42%↘, whereas at S_{14} treated fruits had higher concentrations of linalool, geranylacetone and 6-methyl-5-hepten-2-one (1.06, 52.50 and 79.27 μg · kg^{-1}, respectively). 'Caravaggio' demonstrated the strongest apocarotenoid reduction at S_{14}, whereas 'Top Stellina' was more responsive to KH_2PO_4 (mainly for β-cyclocitral, geranylacetone and total terpenes/terpenoids), thus highlighting the central role of the genotype in responding to other experimental factors. Nonetheless, these results suggest that proper preharvest KH_2PO_4 applications can preserve specific commercial, nutritional and quality traits of cold-stored cherry tomatoes.

Keywords: Cold storage; Fruit quality; Preharvest KH_2PO_4 spraying; *Solanum lycopersicum* L.; Volatile organic compounds

1. Introduction

Tomato (*Solanum lycopersicum* L.) is a widely consumed fruit vegetable and a valuable source of functional compounds, having a multitude of health benefits for consumers (Parisi et al., 2023). The global cultivation area of this species is ~5 Mha (Faostat, 2022), a feature arising from its adaptability to different growth conditions, even far outside its center of origin (Castello et al., 2017). Currently, tomatoes are among the most traded vegetables throughout the world (115 billion USD in 2018) (Boon, 2020) despite their climateric nature and potentially limited shelf life under ambient temperature (Albornoz et al., 2022). Therefore, the year-round tomato demand must be matched with postharvest strategies bridging the spatial and temporal gaps between

* Corresponding author.
E-mail address: rosario.mauro@unict.it

Peer review under responsibility of Chinese Society of Horticultural Science (CSHS) and Institute of Vegetables and Flowers (IVF), Chinese Academy of Agricultural Sciences (CAAS)

https://doi.org/10.1016/j.hpj.2023.12.016

production and consumption. Low-temperature storage (between 8 and 13 °C, depending on duration, fruit typology and ripening stage) is generally considered an effective method to slow water loss and ethylene biosynthesis in tomatoes, thus decreasing their senescence rate. However, due to their tropical origin, tomatoes can suffer chilling injuries below 13 °C, with subsequent metabolic disorders, including adverse effects on the biosynthesis of volatile organic compounds (VOCs) (Distefano et al., 2022a). These represent a heterogeneous class of odor-active constituents, co-responsible for the perception of fruit flavor and highly influenced by external factors, owing to their polygenic nature (Rambla et al., 2014). More than 400 tomato volatiles are known, ~10% of which exhibit major organoleptic relevance (Klee and Tieman, 2013; Zhou et al., 2022). Over the last decades, the interest in these constituents has been growing as a means to improve the nonvisual quality of tomatoes and to counteract the disaffection of consumers, who complain about the poor flavor of modern tomatoes (Klee, 2010). Recent developments in plant genetics have begun to shed light on the molecular determinism of pivotal VOCs, thus leading to a new breeding era favoring more flavorful tomatoes (Tieman et al., 2017). Nonetheless, there is still little knowledge about the agronomic practices able to modulate the tomato volatilome and its evolution during postharvest life. As preharvest factors are highly influential on vegetable physiology during postharvest (Giuffrida et al., 2018), targeting the most suitable cultivation practices can provide opportunities to preserve tomato quality and sensory profiles along the distribution chain. In this view, crop fertilization has a huge influence on the quality of vegetables, with potassium (K) and phosphorus (P) being associated with multiple physiological functions in tomatoes (Daoud et al., 2018; Li et al., 2021). In cherry tomatoes, preharvest supplementation with KCl has been shown to reduce the chill-induced lipid peroxidation during storage at 4 °C, likely a consequence of enhanced concentrations of lycopene and flavonoids (Constán-Aguilar et al., 2014a, 2014b). On the other hand, Ahn et al. (2005) reported that foliar applications of P promote antioxidant enzyme activities in tomato fruits, thus contributing to the protection of cell structures from reactive oxygen species (ROS) and the enhancement of shelf life. More recently, Zahirul et al. (2018) observed that the foliar application of both macronutrients (as KH_2PO_4) prolonged the shelf life of cherry tomatoes stored at 5 °C by reducing their weight loss and respiration rate while enhancing their lycopene content. Despite this evidence, there is no information yet about the effects of targeted applications of both macronutrients on the overall quality of cold-stored tomatoes, especially concerning their volatilome composition. Bridging this knowledge gap may help promote tomato consumption, with positive effects on consumers' eating habits and, potentially, on the incidence of serious noncommunicable diseases (Klee, 2010). For these reasons, this study evaluated the effects of preharvest foliar applications of K and P (as KH_2PO_4) on the compositional traits of cherry tomatoes subjected to refrigerated storage. To this end, we used the fruits of three cultivars widely spread over the reference area and differing for their main fruit traits, and their characteristics (including their volatile composition) were assessed both at harvest and after seven and fourteen days of refrigerated storage, in comparison to untreated controls.

2. Materials and methods

2.1. Experimental site, plant material and growth conditions

The trial was conducted in 2019 at the experimental station of the University of Catania (37°24′26″ N, 15°03′37″ E, 6 m a.s.l.). Three cherry tomato F_1 cultivars ('Caravaggio', 'Sugarland' and 'Top Stellina') (Table S1) were grown in an 810 m^2 greenhouse with a steel tubular frame and covered with polycarbonate panels. On February 11th, plantlets (3 true leaves) were transplanted into an open soilless system consisting of 5 L plastic pots (20 × 19 cm) filled with perlite (2–6 mm particle size) and arranged in a 0.30 × 1.00 m format. Fruit set was promoted through bumblebees, whereas the crop was fertigated with a full-strength Arnon solution.

During cultivation, the plants were foliar sprayed with a solution of KH_2PO_4 (20 mmol · L^{-1}), a generally recognized as safe (GRAS) substance, according to the U.S. Food and Drug Administration (https://www.cfsanappsexternal.fda.gov/scripts/fdcc/?set=SCOGS&sort=GRAS_Substance&order=ASC&type=basic&search=potassium20phosphate). The spraying solutions were obtained by diluting the salt in deionized water. The application rate was fixed on the basis of our previous observations (unpublished data). Sprays were applied between 8:00 and 9:00 a.m. (local solar time) using a manual sprayer, beginning with the complete fruit set of the first cluster and continuing after the fruit set of each of the subsequent seven clusters. Overall, eight treatments were applied weekly from February 27th up to April 17th. Treatments were performed on 9 plants per plot by completely wetting them through the application of 8–30 mL solution per plant, depending on the crop growth stage. Control plants were sprayed with deionized water. Further crop practices included the manual removal of lateral stems, truss pruning (leaving 14 fruits per truss) and the application of *Beauveria bassiana* and Azadirachtin (when needed). All clusters were hand-harvested when fruits reached the red (F) stage (Gautier et al., 2008).

2.2. Fruit sampling and storage conditions

For the postharvest experiment, tomatoes belonging to the 3rd cluster (i.e., those harvested between 6th and 10th May 2019) were used. Specifically, collected clusters were transported to the laboratory soon after harvesting. Overall, 162 clusters (9 clusters × 2 treatments × 3 cultivars × 3 replicates) were divided into 3 main batches for the characterization of fruits belonging to plants either treated or not with KH_2PO_4 and after 0 (harvest date), 7 and 14 days of storage at 8.0 ± 0.5 °C (88 ± 4% RH) (hereafter referred S_0, S_7 and S_{14}, respectively) (Fig. 1). Fruits were detached from the rachis, selected for uniformity and absence of defects (within each cultivar), washed with deionized water and dried with paper. For characterization at S_7 and S_{14}, twelve to twenty-six fruits per replicate were placed in commercial PET trays (Mod. C500/41p; 190 × 115 × 41 mm) (Carton Pack s.p.a., Rutigliano, Italy) for a final net weight of 250 ± 9 g, after which they were stored under the abovementioned conditions. Each experimental unit included 6 trays.

Fig. 1 Temporal evolution of cherry tomatoes appearance as a function of the studied factors

2.3. Determination of main carpometric traits

Fruit fresh weight (g) was gravimetrically determined with an electronic scale (0.01 g accuracy), whereas fruit water content (WTc, expressed on a percentage basis) was determined by reweighing tomatoes after complete desiccation in a thermo-ventilated oven (Binder, Milan, Italy) at 105 °C (~72 h). Fruit pressure firmness (FPF) was measured by using a digital texture analyzer (Stable Micro Systems, Godalming, UK) with a 490 N nominal force load cell and a stainless-steel plate as the probe (100 × 85 × 6 mm). All the tests were performed by applying a deformation force to the stylar end of each fruit (12 fruits per replicate) for up to 2 mm fruit deformation along the longitudinal axis, with a test speed of 10 mm · s^{-1}. Fruit pressure firmness (kPa) was calculated according to the following equation (Brückner and Auerswald, 2019):

$$FPF = (F \times 1000) / \{[(h/2)^2 - (h/2 - d/2)^2] \times 2\pi\}$$

where F is the maximum deformation force recorded during the test, h is the fruit's longitudinal diameter and d is the longitudinal deformation (2 mm).

Total soluble solids (TSS) and titratable acidity (TA) were determined on previously pureed and centrifuged fruits (5 min at 2236 *g*) to obtain a clear juice. TSS (%, at 20 °C) were determined via a digital refractometer (Atago, Tokyo, Japan) equipped with an automatic temperature compensation system. For the analysis of TA, 10 mL of clear tomato juice were titrated with 0.1 M NaOH to pH 8.2 by using phenolphthalein as an indicator until the pink end-point. Titratable acidity was calculated according to the following equation (Teerachaichayut and Ho, 2017):

$$TA\ (\%, \text{citric acid}) = 0.064 \times v$$

where v is the volume of NaOH in milliliter.

The abovementioned determinations allowed for the calculation of the TSS/TA ratio (adimensional).

2.4. Total phenol quantification

The total phenolic content (TPC) of tomato extracts was determined by using 200 mg of freeze-dried, pulverized sample per replicate, which was extracted with 1 mL of methanol (70%) for 1 h at room temperature; each extract was then centrifuged at 5 345 *g* for 5 min (25 °C). An aliquot of 200 μL of supernatant was mixed with 1000 μL of Folin–Ciocâlteu reagent (1: 10 v/v in water); after 2 min, the solution was mixed with 800 μL of Na_2CO_3 solution (5% w/v). Samples were agitated and incubated for 2 min (40 °C). The absorbance was read at 760 nm by using a Jenway 7315 UV–Vis spectrophotometer (Cole–Parmer, Stone, UK). The TPC values were obtained from a standard curve ($r = 0.999***$) obtained by plotting the absorbances of known concentrations of chlorogenic acid. The results were expressed as milligrams (mg) of chlorogenic acid equivalents per kilogram (kg^{-1}) dry weight.

2.5. Total carotenoid quantification

The total carotenoid content (TCC, including xanthophylls) of tomato extracts was determined according to Lichtenthaler and Wellburn (1983), with modifications. Fifty milligrams of lyophilized tomato powder were extracted with 5 mL acetone, vortexed for 1 min and left overnight in the dark (10 °C). Afterward,

samples were sonicated for 20 min in an ultrasonic bath (~6 °C) and centrifuged for 10 min (5345 *g* at 6 °C). The supernatant was collected, and the solid phase was re-extracted twice (2 mL acetone) until it was colorless The absorbance (A) of the supernatant was then measured at 470, 644.8, and 661.6 nm and the obtained values were applied in the following equations (Lichtenthaler and Buschmann, 2001):

$$\text{Chlorophyll A (Chl A)} = 11.24\ A_{661.6} - 2.04\ A_{644.8};$$

$$\text{Chlorophyll B (Chl B)} = 20.13\ A_{644.8} - 4.19\ A_{661.6};$$

$$\text{TCC} = (1000\ A_{470} - 1.90\ \text{Chl A} - 63.14\ \text{Chl B})/214.$$

The results were expressed as mg · kg^{-1} dry weight.

2.6. Antioxidant capacity determination

2.6.1. 2,2-Diphenyl-1-picrylhydrazyl assay

The 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity of tomato extracts was determined according to Brand-Williams et al. (1995) with modifications. 100 mg of lyophilized tomato powder was mixed with 5 mL methanol (80%) and vortexed for 1 min. Samples were then placed into an ultrasonic bath for 10 min (~6 °C) and centrifuged for 15 min at 2 236 *g* (6 °C). For the reaction, 150 μL of supernatant was mixed with 1350 μL of DPPH solution (150 μmol), after which the samples were vortexed (~ 5 s) and placed in the dark (30 min). The decrease in absorbance of the methanolic solution of DPPH was read at 515 nm, and values were obtained from a standard curve (r = 0.999***) obtained via the change in absorbance against different Trolox concentrations. The results were expressed as millimoles (mmol) of Trolox equivalents per kilogram (kg^{-1}) dry weight.

2.6.2. Ferric reducing antioxidant power assay

For the ferric reducing antioxidant power (FRAP) assay (Benzie and Strain, 1999) 200 mg of lyophilized tomato powder was extracted with 10 mL methanol (100%), vortexed for 1 min and placed in the dark for 30 min. Samples were then centrifuged for 10 min at 4 000 *g* (6 °C). The FRAP reagent consisted of 10 mL of acetate buffer (300 mmol, pH 3.1) mixed with 1 mL of 2,4,6-tris(2-pyridyl)-s-triazine (TPTZ) solution (10 mmol in 40 mmol HCl) and 1 mL of ferric chloride (20 mmol). For the reaction, 150 μL of supernatant were mixed with 300 μL of ultrapure water, vortexed and added to 3 mL of FRAP reagent. Samples were placed in the dark for 10 min (20 °C). The FRAP readings were conducted following the shift in absorbance at 593 nm upon the formation of the blue compound Fe(II)-tripyridyltriazine from the colorless oxidized Fe(III) form in the presence of a specific concentration of the sample. The FRAP values were calculated from a standard curve (r = 0.999***) obtained by plotting the change in absorbance against different Trolox concentrations. The results were expressed as millimoles (mmol) of Trolox equivalents per kilogram (kg^{-1}) dry weight.

2.7. Extraction and analysis of volatile compounds

Headspace-solid-phase microextraction coupled with gas chromatography–mass spectrometry (HS-SMPE-GC/MS) was used to analyze the volatile aroma compounds of tomatoes. Specifically, 10 g of chopped fruits were placed in a 40 mL vial with a "mininert" valve (Supelco, Bellefonte, PA, USA), adding 5 mL of saturated NaCl solution. Before extraction, each sample was thermally equilibrated for 30 min (40 °C). Subsequently, a triphasic DVB/CAR/PDMS fiber (Supelco, Bellefonte, PA, USA) with a 50/30 μm film thickness was used for the extraction of the volatiles, which was performed at 40 °C for 30 min under continuous magnetic stirring. Finally, the fiber was directly desorbed into the injector port of the GC/MS at 260 °C for 3 min.

For the analysis, a Shimadzu GC 2010 Plus gas chromatograph interfaced with a TQMS 8040 triple quadrupole mass spectrometer (Shimadzu, Milan, Italy) was used. The following conditions were used for the analysis: injector temperature, 260 °C; injection mode, splitless; capillary column, VF-WAXms, 60 m × 0.25 mm i.d. × 0.25 μm film thickness (Agilent, S.p.a. Milan, Italy); oven temperature, held at 45 °C for 5 min, then increased to 80 °C at a rate of 10 °C · min^{-1} and to 240 °C at 2 °C · min^{-1}; carrier gas, helium at a constant flow of 1 mL · min^{-1}; transfer line temperature, 250 °C; acquisition range, 30–400 m/z; scan speed, 1250 amu · s^{-1}. The volatile compounds were identified through mass spectral data and compared with NIST'18 (NIST/EPA/NIH Mass Spectra Library, version 2.0, Gaithersburg, MD, USA) and the FFNSC 3.0 database, as well as with linear retention indices (LRIs) and injected standards.

The concentration of each compound was determined by the external standard method. Stock solutions of individual standards were prepared by dissolving the appropriate amount of each standard compound in ethyl alcohol (95%) to obtain a final concentration of 0.1 mg · mL^{-1}. Furthermore, five different amounts of each stock solution were injected with the same analytical conditions used for analyzing tomato samples, and a calibration curve was generated by plotting the detector response versus the amount of each standard. The peak area of each compound was determined for three replicates, and the average value was calculated. The standards were purchased from Sigma Aldrich s.r.l. (Milan, Italy) at the highest purity available. To quantify those compounds with unavailable standards, the calibration curve of a compound of the same chemical class with the most similar retention time was used. All volatile concentrations were expressed as μg · kg^{-1} on a fresh weight basis.

2.8. Statistical procedures

All collected and calculated data were firstly subjected to Shapiro–Wilk's and Levene's test, to check for normal distribution and homoscedasticity, respectively, then to a factorial 'treatment × genotype × storage time' analysis of variance (ANOVA), according to the randomized blocks design adopted in the experiment. Percentage data were Bliss transformed before the ANOVA (untransformed data are reported), whereas means were compared through the Tukey's HSD test ($P \leq 0.05$). Standardized fruit traits were subjected to principal component analysis (PCA, one per storage time) to determine the most effective traits in discriminating between treatments and cultivars. The first two components explaining the maximum variance were selected for the analysis, and the correlation between the original traits and the corresponding principal component was calculated. All calculations were performed using Excel

Table 1 Carpometric traits of cherry tomato fruits as affected by the studied factors

	Fruit weight (g)	Fruit WTc (%)	FPF (kPa)	TSS (%)	TA (%)	TSS/TA (adimensional)
Source of variation						
Treatment						
Control	13.75 ± 3.28 a	89.4 ± 1.2 a	56.9 ± 19.9 b	8.99 ± 1.09 b	0.347 ± 0.036 b	25.8 ± 2.4 a
Treated	14.91 ± 2.95 a	90.0 ± 1.0 a	60.5 ± 23.0 a	9.37 ± 0.88 a	0.370 ± 0.030 a	25.7 ± 3.4 a
Genotype						
'Caravaggio'	17.26 ± 2.89 a	89.7 ± 0.8 ab	84.7 ± 16.7 a	8.58 ± 0.70 b	0.349 ± 0.040 b	24.8 ± 2.4 b
'Sugarland'	12.50 ± 2.27 b	88.5 ± 1.2 b	34.6 ± 15.6 c	8.89 ± 0.80 b	0.368 ± 0.036 a	24.3 ± 2.3 b
'Top Stellina'	13.22 ± 2.60 b	91.0 ± 0.6 a	56.7 ± 18.5 b	10.06 ± 0.82 a	0.359 ± 0.024 ab	28.1 ± 2.4 a
Storage time						
S_0	15.49 ± 3.44 a	90.2 ± 1.0 a	62.4 ± 10.1 a	9.37 ± 0.66 a	0.382 ± 0.030 a	24.7 ± 2.5 b
S_7	14.11 ± 3.56 b	90.1 ± 0.9 a	58.3 ± 11.6 b	9.67 ± 0.97 a	0.357 ± 0.027 b	27.2 ± 3.2 a
S_{14}	13.38 ± 2.16 b	88.8 ± 1.4 b	55.3 ± 12.9 b	8.50 ± 0.97 b	0.336 ± 0.031 c	25.4 ± 2.5 ab
Treatment × Genotype						
Control 'Caravaggio'	17.10 ± 2.86	89.6 ± 1.1	80.7 ± 15.9	8.36 ± 0.83	0.317 ± 0.029	26.4 ± 1.8
Control 'Sugarland'	11.92 ± 2.13	87.7 ± 1.8	34.3 ± 14.8	8.66 ± 1.02	0.358 ± 0.034	24.3 ± 2.8
Control 'Top Stellina'	12.22 ± 1.66	91.0 ± 1.6	55.6 ± 12.8	9.94 ± 0.73	0.371 ± 0.023	26.8 ± 1.8
Treated 'Caravaggio'	17.43 ± 3.02	89.8 ± 0.5	88.7 ± 14.9	8.81 ± 0.47	0.380 ± 0.020	23.3 ± 1.9
Treated 'Sugarland'	13.07 ± 3.49	89.4 ± 1.1	34.9 ± 16.6	9.11 ± 0.47	0.377 ± 0.038	24.3 ± 1.8
Treated 'Top Stellina'	14.21 ± 1.68	90.9 ± 0.6	57.8 ± 11.5	10.18 ± 0.93	0.346 ± 0.020	29.4 ± 2.3
HSD interaction	NS	NS	4.3**	NS	0.033***	2.8***
Treatment × Storage time						
Control S_0	15.18 ± 3.02	90.0 ± 1.2	61.4 ± 10.6	9.38 ± 0.66	0.376 ± 0.029	25.0 ± 2.0
Control S_7	13.30 ± 3.07	89.9 ± 1.1	56.7 ± 10.1	9.62 ± 0.77	0.346 ± 0.024	27.8 ± 1.6
Control S_{14}	12.77 ± 3.57	88.3 ± 2.3	52.5 ± 10.2	7.96 ± 1.00	0.324 ± 0.037	24.6 ± 2.3
Treated S_0	15.80 ± 3.97	90.5 ± 1.7	63.5 ± 10.8	9.35 ± 0.71	0.388 ± 0.032	24.3 ± 2.9
Treated S_7	14.93 ± 2.72	90.3 ± 1.8	59.9 ± 14.1	9.71 ± 1.18	0.368 ± 0.026	26.6 ± 4.3
Treated S_{14}	13.99 ± 2.76	89.3 ± 1.2	58.0 ± 16.2	9.04 ± 0.59	0.348 ± 0.020	26.1 ± 2.6
HSD interaction	NS	NS	NS	0.63**	NS	1.5*
Genotype × Storage time						
'Caravaggio' S_0	17.94 ± 2.53	90.0 ± 0.8	87.8 ± 14.4	8.77 ± 0.15	0.368 ± 0.028	24.0 ± 2.2
'Caravaggio' S_7	17.11 ± 2.85	89.9 ± 0.3	84.3 ± 17.3	8.96 ± 0.15	0.355 ± 0.035	25.5 ± 2.7
'Caravaggio' S_{14}	16.75 ± 2.05	89.1 ± 1.1	82.1 ± 17.7	8.02 ± 1.01	0.323 ± 0.047	25.0 ± 2.4
'Sugarland' S_0	14.19 ± 3.74	89.6 ± 0.9	40.9 ± 12.6	9.32 ± 0.40	0.407 ± 0.021	23.0 ± 1.6
'Sugarland' S_7	12.42 ± 1.34	89.4 ± 0.9	34.0 ± 12.4	9.23 ± 0.44	0.358 ± 0.028	25.9 ± 2.2
'Sugarland' S_{14}	10.89 ± 2.34	86.6 ± 0.9	28.7 ± 12.0	8.11 ± 0.87	0.337 ± 0.015	24.0 ± 2.2
'Top Stellina' S_0	14.34 ± 1.76	91.2 ± 0.3	58.6 ± 11.6	10.01 ± 0.63	0.370 ± 0.028	27.1 ± 1.4
'Top Stellina' S_7	12.81 ± 1.87	91.0 ± 0.2	56.6 ± 11.9	10.81 ± 0.75	0.358 ± 0.020	30.2 ± 2.3
'Top Stellina' S_{14}	12.51 ± 1.52	90.7 ± 0.9	55.0 ± 12.8	9.37 ± 0.31	0.347 ± 0.023	27.1 ± 2.1
HSD interaction	NS	1.3*	3.9*	NS	0.023*	NS
Overall mean	14.33 ± 3.14	89.7 ± 1.7	58.7 ± 11.3	9.18 ± 1.03	0.380 ± 0.035	25.7 ± 2.9

Note: Each value represents the mean ± standard deviation ($n = 3$). Different letters within the main factors indicate significance at Tukey's HSD test ($P \leq 0.05$). *, ** and ***: significant at $P = 0.05$, 0.01 and 0.001, respectively. NS: not significant. WTc: water content; FPF: fruit pressure firmness; TSS: total soluble solids; TA: titratable acidity.

version 2016 (Microsoft Corporation, Redmond, WA, USA) and Minitab version 16.1.1 (Minitab Inc., State College, PA, USA).

The significance resulting from the ANOVA related to treatment (T), genotype (G), storage time (S) and their first order interactions is reported in Table S2 (Fisher-Snedecor F-test and their incidence on total sum of squares), and their effects on variable means are reported in Tables 1–6 and Figs. 1–2.

3. Results

3.1. Main carpometric traits

The KH_2PO_4 application promoted FPF, TSS and TA, but in many cases, the responses of the carpometric variables were affected by the interactions with genotype and storage time (Table 1). Indeed, considering the genotypic response to the treatment, 'Caravaggio' proved the highest increase in FPF (80.7 vs. 88.7 kPa, +10%) and TA (0.317 vs. 0.380%), along with a significant reduction in TSS/TA (26.4 vs. 23.3, −12%); differently, 'Top Stellina' maximized the increase in TSS/TA (26.8 vs. 29.4, +10%) (Table 1). The progression of storage time led to a reduction for fruit weight, WTc, FPF, TSS and TA; between S_7 and S_{14}, control fruits showed the strongest decrease in terms of TSS (from 9.62 to 7.96, −17%) and TSS/TA (from 27.8 to 24.6, −12%) (Table 1). Regarding the 'genotype × storage time' interaction, 'Sugarland' highlighted the most pronounced decrease in fruit WTc (from 89.4 to 86.6%, passing from S_7 to S_{14}) and FPF (from 40.9 to 34.0 to 28.7 kPa, passing from S_0 to S_7 and then to S_{14}), together with the steepest decline in TA along the S_0–S_{14} period (from 4.07 to 3.37%) (Table 1).

3.2. Functional variables

The preharvest foliar spraying significantly enhanced all fruit functional variables, yet these variables exhibited a progressive decline throughout the storage period (Table 2). The significant 'treatment × genotype' interaction revealed that, compared to control fruits, in 'Caravaggio' and 'Top Stellina' the KH_2PO_4 application generated the strongest raises in TCC (which passed from 168 to 214 mg · kg^{-1} and from 218 to 239 mg · kg^{-1}, respectively) and FRAP (from 36.8 to 49.3 mmol · kg^{-1} and from

Table 2 Functional traits of cherry tomato fruits as affected by the studied factors

	TPC (mg · kg^{-1})	TCC (mg · kg^{-1})	DPPH (mmol · kg^{-1})	FRAP (mmol · kg^{-1})
Source of variation				
Treatment				
Control	3758 ± 464 b	242 ± 104 b	46.2 ± 5.7 b	38.1 ± 6.6 b
Treated	4223 ± 555 a	268 ± 95 a	50.4 ± 6.1 a	44.6 ± 10.1 a
Genotype				
'Caravaggio'	4332 ± 632 a	191 ± 48 c	53.6 ± 5.6 a	43.1 ± 8.1 a
'Sugarland'	3898 ± 438 b	345 ± 69 a	47.6 ± 4.8 b	42.6 ± 5.8 a
'Top Stellina'	3743 ± 429 b	228 ± 57 b	43.8 ± 3.8 c	38.5 ± 6.1 b
Storage time				
S_0	3769 ± 453 b	219 ± 41 b	44.3 ± 3.6 c	42.1 ± 5.2 a
S_7	4064 ± 723 a	344 ± 74 a	48.1 ± 4.7 b	45.9 ± 7.1 a
S_{14}	4139 ± 404 a	201 ± 59 b	52.5 ± 7.0 a	36.2 ± 5.9 b
Treatment × Genotype				
Control 'Caravaggio'	3939 ± 414	168 ± 39	51.9 ± 4.7	36.8 ± 7.6
Control 'Sugarland'	3800 ± 529	339 ± 60	45.4 ± 4.0	41.1 ± 5.9
Control 'Top Stellina'	3537 ± 394	218 ± 65	41.4 ± 1.6	36.5 ± 5.9
Treated 'Caravaggio'	4725 ± 573	214 ± 46	55.3 ± 6.1	49.3 ± 4.8
Treated 'Sugarland'	3996 ± 325	350 ± 74	49.7 ± 4.7	44.1 ± 5.6
Treated 'Top Stellina'	3948 ± 375	239 ± 51	46.2 ± 4.0	40.4 ± 6.0
HSD interaction	NS	16*	NS	2.6*
Treatment × Storage time				
Control S_0	3540 ± 422	211 ± 47	43.1 ± 3.8	40.1 ± 5.6
Control S_7	3796 ± 565	331 ± 93	46.3 ± 4.9	39.5 ± 7.0
Control S_{14}	3939 ± 333	183 ± 63	49.2 ± 6.7	34.8 ± 6.6
Treated S_0	3998 ± 376	227 ± 33	45.5 ± 3.2	44.0 ± 4.2
Treated S_7	4333 ± 793	358 ± 89	49.9 ± 4.1	52.3 ± 8.8
Treated S_{14}	4339 ± 382	218 ± 53	55.8 ± 6.0	37.5 ± 5.1
HSD interaction	NS	16*	2.4*	2.6*
Genotype × Storage time				
'Caravaggio' S_0	3938 ± 503	187 ± 28	48.5 ± 2.2	40.0 ± 5.9
'Caravaggio' S_7	4756 ± 676	239 ± 38	52.7 ± 2.7	55.0 ± 5.3
'Caravaggio' S_{14}	4302 ± 494	147 ± 29	59.6 ± 4.3	34.2 ± 6.1
'Sugarland' S_0	3756 ± 499	269 ± 24	43.0 ± 1.7	43.8 ± 4.8
'Sugarland' S_7	3859 ± 459	492 ± 27	48.5 ± 1.8	45.2 ± 5.2
'Sugarland' S_{14}	4079 ± 356	274 ± 26	51.2 ± 5.5	38.8 ± 6.1
'Top Stellina' S_0	3613 ± 364	202 ± 22	41.5 ± 2.2	42.3 ± 5.1
'Top Stellina' S_7	3578 ± 448	302 ± 28	43.1 ± 3.1	37.5 ± 6.5
'Top Stellina' S_{14}	4038 ± 369	181 ± 19	46.8 ± 4.3	35.5 ± 5.4
HSD interaction	458*	35***	2.9*	4.3**
Overall mean	3991 ± 458	255 ± 90	48.3 ± 6.2	41.4 ± 9.1

Note: Each value represents the mean ± standard deviation ($n = 3$). Different letters within the main factors indicate significance at Tukey's HSD test ($P \leq 0.05$). *, ** and ***: significant at $P = 0.05$, 0.01 and 0.001, respectively. NS: not significant. TPC: total phenolic content; TCC: total carotenoid content; DPPH: 2,2-diphenyl-1-picrylhydrazyl radical scavenging activity; FRAP: ferric reducing antioxidant power assay.

36.5 to 40.4 mmol · kg^{-1}, respectively) (Table 2). Passing from S_7 to S_{14}, control fruits showed a stronger TCC reduction (from 331 to 183 mg · kg^{-1}, -45%) than treated fruits (from 358 to 218 mg · kg^{-1}, -39%) (Table 2). On the other hand, the DPPH values were notably higher in treated fruits at S_7 (46.3 vs. 49.9 mmol · kg^{-1}, +8%) and S_{14} (49.2 vs. 55.8 mmol · kg^{-1}, +13%), while the differences in FRAP values among control and treated fruits were particularly pronounced at S_7 (39.5 vs. 52.3 mmol · kg^{-1}, +32%) (Table 2). Concerning the genotypic behavior over time, significant TPC increases were noticed in 'Caravaggio' (3938 vs. 4756 mg · kg^{-1} progressing from S_0 to S_7) and 'Top Stellina' (3578 vs. 4038 mg · kg^{-1} from S_7 to S_{14}), whereas wider TCC variations were recorded in 'Sugarland' and 'Top Stellina' passing from S_0 to S_7 (from 269 to 492 mg · kg^{-1} and from 202 to 302 mg · kg^{-1}, respectively), and then to S_{14} (274 and 181 mg · kg^{-1}, respectively) (Table 2). Regarding the fruits' antioxidant capacity, 'Caravaggio' and 'Sugarland' showed the most marked DPPH increase over the S_0–S_{14} period (from 48.5 to 59.6 mmol · kg^{-1} and from 43.0 to 51.2 mmol · kg^{-1}, respectively) along with a significant FRAP decline moving from S_7 (55.0 and 45.2 mmol · kg^{-1}, respectively) to S_{14} (34.2 and 38.8 mmol · kg^{-1}, respectively) (Table 2).

3.3. *Volatile composition*

Among the many compounds identified, 32 VOCs, which are considered key tomato aroma contributors (Petró-Turza, 1986), were always present in all samples. They consisted of 16 aldehydes, 7 terpenes/terpenoids, 2 alcohols and 3 ketones, along with 4 other compounds (2 organic acids, 1 furan and 1 thiazole) grouped together as other volatiles (Tables 3–6). All 32 compounds, along with their descriptions and identification methods, are reported in Table S3.

3.3.1. *Aldehyde volatiles*

The application of KH_2PO_4 increased the concentrations of 9 out of 16 aldehydes along with the total aldehydes concentration while decreasing those of nonanal, decanal, and undecanal (Table 3). The genotypic responses to the treatment revealed

Table 3 Volatile aldehydes concentration in cherry tomato fruits ($\mu g \cdot kg^{-1}$) as affected by the studied factor

Chemical class	Aldehydes							
	Pentanal	Hexanal	(E)-2-Hexenal	(Z)-3-Hexenal	Benzaldehyde	Heptanal	(E,E)-2,4-Heptadienal	(Z)-2-Heptenal
Source of variation								
Treatment								
Control	3.40 ± 2.42 b	478 ± 310 b	120 ± 28 b	22.7 ± 8.2 b	2.76 ± 1.76 b	8.04 ± 2.05 b	0.49 ± 0.13 b	18.8 ± 4.2 a
Treated	4.80 ± 2.07 a	736 ± 237 a	147 ± 25 a	27.0 ± 9.9 a	4.01 ± 2.47 a	11.32 ± 3.59 a	0.90 ± 0.31 a	18.1 ± 3.3 a
Genotype								
'Caravaggio'	2.64 ± 1.46 b	491 ± 263 b	145 ± 36 a	35.3 ± 8.0 a	1.99 ± 0.81 c	8.16 ± 2.92 c	0.71 ± 0.36 a	16.4 ± 2.7 b
'Sugarland'	5.20 ± 2.91 a	406 ± 172 c	124 ± 26 b	22.5 ± 8.2 b	5.87 ± 1.14 a	11.13 ± 3.76 a	0.67 ± 0.17 a	17.7 ± 2.9 b
'Top Stellina'	4.46 ± 1.69 a	923 ± 156 a	132 ± 24 ab	16.8 ± 8.3 c	2.30 ± 0.51 b	9.76 ± 3.02 b	0.72 ± 0.39 a	21.3 ± 3.8 a
Storage time								
S_0	4.32 ± 3.12 ab	695 ± 264 a	143 ± 27 a	31.0 ± 11.8 a	3.61 ± 2.17 b	11.20 ± 3.26 a	0.86 ± 0.42 a	18.5 ± 4.7 a
S_7	4.69 ± 1.22 a	664 ± 309 a	143 ± 30 a	22.1 ± 10.8 b	4.06 ± 2.82 a	9.67 ± 3.98 b	0.67 ± 0.23 b	19.0 ± 2.7 a
S_{14}	3.29 ± 2.18 b	462 ± 295 b	115 ± 24 b	21.5 ± 8.5 b	2.49 ± 1.14 c	8.17 ± 2.48 c	0.57 ± 0.18 b	17.8 ± 3.7 a
Treatment × Genotype								
Control 'Caravaggio'	1.97 ± 1.03	279 ± 143	126 ± 37	35.2 ± 8.5	1.48 ± 0.41	6.26 ± 3.93	0.44 ± 0.10	16.6 ± 3.1
Control 'Sugarland'	4.32 ± 2.51	291 ± 120	109 ± 18	15.5 ± 4.9	4.79 ± 1.62	9.98 ± 2.57	0.58 ± 0.14	17.5 ± 2.8
Control 'Top Stellina'	3.91 ± 0.97	863 ± 165	124 ± 27	17.5 ± 9.7	2.00 ± 0.37	7.89 ± 4.83	0.46 ± 0.10	22.2 ± 4.4
Treated 'Caravaggio'	3.30 ± 1.10	703 ± 160	163 ± 26	35.5 ± 8.0	2.51 ± 0.80	10.05 ± 3.01	0.97 ± 0.32	16.2 ± 2.3
Treated 'Sugarland'	6.08 ± 1.98	522 ± 135	139 ± 25	29.4 ± 5.3	6.94 ± 2.13	12.28 ± 2.58	0.75 ± 0.15	18.0 ± 3.3
Treated 'Top Stellina'	5.02 ± 2.01	984 ± 127	140 ± 18	16.1 ± 5.7	2.60 ± 0.45	11.63 ± 1.79	0.98 ± 0.38	20.3 ± 3.1
HSD interaction	NS	143***	NS	7.5***	0.94***	NS	0.24**	NS
Treatment × Storage time								
Control S_0	3.88 ± 1.64	608 ± 321	129 ± 26	31.2 ± 9.6	2.73 ± 1.38	10.23 ± 3.5	0.56 ± 0.15	19.8 ± 5.6
Control S_7	4.28 ± 1.81	508 ± 288	131 ± 31	19.2 ± 8.2	3.45 ± 2.50	8.25 ± 3.36	0.48 ± 0.09	18.6 ± 2.4
Control S_{14}	2.04 ± 0.80	317 ± 280	99 ± 15	17.8 ± 8.6	2.08 ± 0.93	5.64 ± 4.21	0.44 ± 0.13	17.9 ± 4.3
Treated S_0	4.76 ± 1.64	782 ± 167	157 ± 22	30.8 ± 9.7	4.48 ± 2.52	12.18 ± 2.61	1.16 ± 0.39	17.2 ± 3.4
Treated S_7	5.10 ± 1.46	820 ± 257	154 ± 25	24.9 ± 8.1	4.67 ± 3.13	11.08 ± 1.76	0.86 ± 0.15	19.4 ± 3.1
Treated S_{14}	4.53 ± 1.16	607 ± 243	130 ± 21	25.2 ± 7.0	2.89 ± 1.23	10.70 ± 3.26	0.69 ± 0.13	17.8 ± 3.3
HSD interaction	NS	80*	NS	4.2*	0.53*	1.78*	0.17*	NS
Genotype × Storage time								
'Caravaggio' S_0	1.64 ± 0.71	598 ± 196	144 ± 36	42.9 ± 6.1	2.72 ± 0.88	11.43 ± 2.68	0.89 ± 0.50	16.3 ± 2.1
'Caravaggio' S_7	3.75 ± 0.90	546 ± 211	172 ± 22	34.7 ± 4.3	1.74 ± 0.48	8.77 ± 2.39	0.68 ± 0.27	18.0 ± 2.6
'Caravaggio' S_{14}	2.53 ± 1.15	329 ± 127	118 ± 30	28.3 ± 5.9	1.51 ± 0.48	4.28 ± 1.42	0.55 ± 0.21	14.9 ± 2.7
'Sugarland' S_0	7.63 ± 2.59	500 ± 176	140 ± 29	25.8 ± 9.6	6.08 ± 1.93	8.86 ± 2.85	0.74 ± 0.20	16.1 ± 2.4
'Sugarland' S_7	5.47 ± 1.44	459 ± 112	126 ± 21	19.3 ± 7.1	7.72 ± 1.42	12.18 ± 1.70	0.62 ± 0.11	19.6 ± 3.0
'Sugarland' S_{14}	2.49 ± 1.17	260 ± 101	106 ± 18	22.2 ± 7.9	3.81 ± 0.80	12.34 ± 2.39	0.63 ± 0.18	17.6 ± 2.7
'Top Stellina' S_0	3.70 ± 1.45	988 ± 185	147 ± 18	24.4 ± 9.6	2.03 ± 0.46	13.33 ± 2.56	0.95 ± 0.52	23.2 ± 4.9
'Top Stellina' S_7	4.85 ± 0.82	987 ± 154	130 ± 24	12.2 ± 3.2	2.73 ± 0.43	8.05 ± 3.70	0.69 ± 0.30	19.5 ± 2.8
'Top Stellina' S_{14}	4.84 ± 1.02	796 ± 149	119 ± 23	13.9 ± 5.0	2.14 ± 0.37	7.89 ± 3.44	0.52 ± 0.17	21.0 ± 3.1
HSD interaction	1.85***	NS	23*	5.1*	1.15***	3.87***	NS	NS
Overall mean	4.10 ± 2.34	607 ± 303	133 ± 30	24.9 ± 11.2	3.39 ± 2.22	9.68 ± 3.75	0.70 ± 0.31	18.5 ± 3.8

(*continued on next page*)

Table 3 – (*continued*)

Chemical class	Aldehydes								
	Octanal	(E)-2-Octenal	Nonanal	(E)-2-Nonenal	Decanal	(E,E)-2,4-Decadienal	Undecanal	Dodecanal	Total aldehydes
Source of variation									
Treatment									
Control	7.95 ± 2.49 b	10.22 ± 3.01 a	27.8 ± 9.7 a	1.54 ± 0.41 a	10.19 ± 4.74 a	0.73 ± 0.54 b	2.31 ± 1.00 a	1.03 ± 0.64 a	715 ± 230 b
Treated	10.19 ± 2.82 a	9.66 ± 2.33 a	20.9 ± 7.6 b	1.34 ± 0.39 a	7.91 ± 4.58 b	0.96 ± 0.60 a	1.96 ± 0.64 b	0.95 ± 0.46 a	1003 ± 345 a
Genotype									
'Caravaggio'	7.44 ± 2.19 c	7.75 ± 1.87 c	23.9 ± 5.1 b	1.45 ± 0.29 a	13.00 ± 4.28 a	0.69 ± 0.28 b	2.54 ± 0.98 a	0.77 ± 0.43 b	758 ± 303 b
'Sugarland'	11.16 ± 3.62 a	11.87 ± 2.42 a	27.4 ± 9.0 a	1.29 ± 0.39 a	5.26 ± 2.04 c	1.43 ± 0.57 a	1.65 ± 0.58 b	1.17 ± 0.54 a	654 ± 207 c
'Top Stellina'	8.60 ± 3.14 b	10.21 ± 2.00 b	21.8 ± 7.1 b	1.57 ± 0.50 a	8.88 ± 2.61 b	0.41 ± 0.19 c	2.21 ± 0.75 a	1.02 ± 0.62 a	1165 ± 188 a
Storage time									
S_0	12.06 ± 2.78 a	10.4 ± 3.06 a	30.1 ± 9.1 a	1.53 ± 0.54 a	9.68 ± 4.88 a	1.10 ± 0.62 a	2.21 ± 0.77 a	1.04 ± 0.46 ab	976 ± 284 a
S_7	8.48 ± 2.79 b	9.84 ± 2.30 a	23.9 ± 8.7 b	1.48 ± 0.26 a	9.65 ± 4.55 a	0.88 ± 0.56 b	2.39 ± 0.92 a	1.06 ± 0.50 a	924 ± 307 a
S_{14}	6.66 ± 3.01 c	9.58 ± 2.72 a	19.1 ± 5.3 c	1.31 ± 0.38 a	7.81 ± 3.60 b	0.56 ± 0.43 c	1.80 ± 0.80 b	0.87 ± 0.69 b	678 ± 309 b
Treatment × Genotype									
Control 'Caravaggio'	5.84 ± 3.32	7.25 ± 1.51	26.7 ± 5.1	1.43 ± 0.27	14.21 ± 5.00	0.60 ± 0.27	2.84 ± 0.92	0.67 ± 0.37	526 ± 182
Control 'Sugarland'	9.97 ± 2.41	12.57 ± 2.42	31.2 ± 8.0	1.44 ± 0.37	6.88 ± 1.20	1.21 ± 0.47	1.83 ± 0.54	1.22 ± 0.57	519 ± 151
Control 'Top Stellina'	8.02 ± 5.04	10.85 ± 2.18	25.6 ± 9.1	1.74 ± 0.52	9.47 ± 2.14	0.39 ± 0.11	2.25 ± 0.95	1.21 ± 0.79	1101 ± 216
Treated 'Caravaggio'	9.05 ± 1.47	8.25 ± 2.14	21.1 ± 3.3	1.48 ± 0.32	11.8 ± 4.48	0.78 ± 0.28	2.23 ± 0.57	0.88 ± 0.48	990 ± 201
Treated 'Sugarland'	12.35 ± 2.38	11.17 ± 2.33	23.7 ± 8.7	1.13 ± 0.36	3.65 ± 1.23	1.66 ± 0.37	1.47 ± 0.59	1.12 ± 0.54	790 ± 163
Treated 'Top Stellina'	9.18 ± 3.20	9.57 ± 1.69	17.9 ± 8.9	1.41 ± 0.45	8.28 ± 3.02	0.44 ± 0.24	2.17 ± 0.53	0.84 ± 0.36	1230 ± 138
HSD interaction	NS	NS	NS	NS	NS	NS	NS	0.26*	177***
Treatment × Storage time									
Control S_0	11.74 ± 3.14	10.95 ± 3.75	37.0 ± 8.6	1.66 ± 0.55	11.69 ± 6.77	1.02 ± 0.62	2.32 ± 0.94	0.98 ± 0.42	883 ± 256
Control S_7	7.34 ± 2.80	9.96 ± 2.55	24.5 ± 8.4	1.54 ± 0.24	9.97 ± 4.04	0.79 ± 0.55	2.76 ± 1.06	1.13 ± 0.56	751 ± 157
Control S_{14}	4.75 ± 2.46	9.76 ± 2.83	22.0 ± 4.4	1.40 ± 0.39	8.90 ± 2.56	0.38 ± 0.14	1.84 ± 0.89	1.00 ± 0.41	512 ± 185
Treated S_0	12.39 ± 2.52	9.84 ± 2.26	23.1 ± 5.9	1.39 ± 0.52	7.67 ± 4.32	1.17 ± 0.64	2.09 ± 0.60	1.11 ± 0.51	1068 ± 159
Treated S_7	9.61 ± 2.42	9.73 ± 2.18	23.4 ± 9.5	1.42 ± 0.27	9.34 ± 5.24	0.98 ± 0.59	2.02 ± 0.61	0.99 ± 0.45	1098 ± 177
Treated S_{14}	8.57 ± 2.23	9.41 ± 2.78	16.2 ± 4.8	1.21 ± 0.36	6.72 ± 4.27	0.73 ± 0.55	1.76 ± 0.74	0.74 ± 0.34	844 ± 146
HSD interaction	1.63*	NS	7.0***	NS	NS	NS	NS	NS	100*
Genotype × Storage time									
'Caravaggio' S_0	9.53 ± 2.28	8.01 ± 2.81	24.8 ± 5.1	1.29 ± 0.20	16.64 ± 2.94	0.92 ± 0.22	1.65 ± 0.44	1.03 ± 0.53	881 ± 232
'Caravaggio' S_7	6.82 ± 1.99	8.39 ± 1.11	25.9 ± 5.5	1.60 ± 0.23	15.30 ± 1.99	0.73 ± 0.26	3.34 ± 0.92	0.86 ± 0.27	848 ± 324
'Caravaggio' S_{14}	5.98 ± 1.60	6.84 ± 1.08	21.0 ± 4.0	1.47 ± 0.36	7.07 ± 1.47	0.42 ± 0.18	2.63 ± 0.68	0.43 ± 0.19	545 ± 266
'Sugarland' S_0	12.84 ± 2.61	11.17 ± 3.09	29.0 ± 9.3	1.32 ± 0.53	5.80 ± 1.77	1.81 ± 0.47	2.04 ± 0.55	1.34 ± 0.26	770 ± 198
'Sugarland' S_7	11.59 ± 1.88	12.20 ± 2.40	31.9 ± 5.2	1.41 ± 0.34	5.23 ± 1.23	1.55 ± 0.35	1.71 ± 0.51	1.66 ± 0.26	717 ± 154
'Sugarland' S_{14}	9.06 ± 2.03	12.23 ± 1.92	21.4 ± 5.2	1.12 ± 0.25	4.76 ± 2.97	0.95 ± 0.55	1.21 ± 0.38	0.52 ± 0.19	477 ± 154
'Top Stellina' S_0	13.82 ± 1.47	12.00 ± 1.94	36.3 ± 9.5	1.97 ± 0.56	6.60 ± 1.61	0.57 ± 0.21	2.93 ± 0.70	0.76 ± 0.42	1277 ± 103
'Top Stellina' S_7	7.03 ± 1.26	8.94 ± 0.93	14.0 ± 2.6	1.42 ± 0.18	8.43 ± 1.14	0.37 ± 0.15	2.12 ± 0.24	0.66 ± 0.15	1208 ± 190
'Top Stellina' S_{14}	4.95 ± 1.66	9.68 ± 1.71	14.9 ± 3.7	1.33 ± 0.47	11.60 ± 1.99	0.31 ± 0.16	1.57 ± 0.50	1.66 ± 0.63	1011 ± 166
HSD interaction	3.55***	NS	8.6***	NS	3.77***	NS	1.04***	0.57***	NS
Overall mean	9.07 ± 3.61	9.94 ± 2.68	24.4 ± 9.3	1.44 ± 0.41	9.05 ± 4.76	0.85 ± 0.58	2.13 ± 0.85	0.99 ± 0.55	859 ± 322

Note: Each value represents the mean ± standard deviation ($n = 3$). Different letters within the main factors indicate significance at Tukey's HSD test ($P \leq 0.05$). *, ** and ***: significant at $P = 0.05$, 0.01 and 0.001, respectively. NS: not significant.

Table 4 Volatile terpenes and terpenoids concentration in cherry tomato fruits ($\mu g \cdot kg^{-1}$) as affected by the studied factors

Chemical class	Terpenes/terpenoids							
	(E)-Citral	(Z)-Citral	β-Cyclocitral	D-Limonene	Linalool	(E)-β-Ionone	Geranylacetone	Total terpenes/terpenoids
Source of variation								
Treatment								
Control	23.1 ± 7.2 b	7.47 ± 3.30 a	15.4 ± 4.1 a	3.67 ± 4.40 a	1.25 ± 0.74 a	3.63 ± 1.35 b	44.1 ± 8.8 b	99 ± 21 b
Treated	27.0 ± 9.0 a	6.03 ± 2.04 b	15.1 ± 4.9 a	3.59 ± 4.03 a	1.21 ± 0.58 a	4.24 ± 1.20 a	52.5 ± 10.1 a	110 ± 21 a
Genotype								
'Caravaggio'	21.2 ± 7.3 c	5.83 ± 2.36 b	15.6 ± 4.4 b	0.71 ± 0.48 c	0.95 ± 0.36 b	3.78 ± 0.96 b	41.5 ± 8.0 c	90 ± 19 c
'Sugarland'	29.3 ± 9.3 a	8.45 ± 3.65 a	12.7 ± 3.3 c	3.76 ± 1.57 b	0.80 ± 0.19 c	3.42 ± 1.02 b	48.3 ± 8.5 b	107 ± 19 b
'Top Stellina'	24.6 ± 5.9 b	5.97 ± 2.09 b	17.4 ± 4.5 a	6.4 ± 2.52 a	1.94 ± 0.62 a	4.61 ± 1.74 a	55.2 ± 9.8 a	116 ± 18 a
Storage time								
S_0	18.5 ± 5.3 c	4.79 ± 1.18 c	14.8 ± 4.1 ab	7.39 ± 3.36 a	1.44 ± 0.92 a	4.35 ± 1.90 a	47.3 ± 9.3 a	99 ± 29 b
S_7	31.3 ± 8.2 a	8.89 ± 2.40 a	16.4 ± 3.6 a	2.18 ± 0.79 b	1.28 ± 0.53 b	4.23 ± 0.63 a	50.8 ± 7.9 a	115 ± 14 a
S_{14}	25.5 ± 5.7 b	6.57 ± 1.67 b	14.5 ± 3.1 b	1.30 ± 0.51 c	0.97 ± 0.33 c	3.21 ± 0.57 b	46.8 ± 9.0 a	99 ± 14 b
Treatment × Genotype								
Control 'Caravaggio'	19.0 ± 5.9	6.60 ± 2.82	16.0 ± 5.8	0.67 ± 0.24	0.97 ± 0.39	3.60 ± 0.56	40.7 ± 9.8	88 ± 22
Control 'Sugarland'	27.9 ± 8.8	9.58 ± 3.33	14.5 ± 2.9	3.87 ± 0.98	0.74 ± 0.16	2.94 ± 0.99	43.1 ± 7.4	103 ± 21
Control 'Top Stellina'	22.4 ± 4.7	6.23 ± 1.09	15.7 ± 3.4	6.45 ± 1.91	2.04 ± 0.73	4.34 ± 1.88	48.5 ± 8.1	106 ± 18
Treated 'Caravaggio'	23.4 ± 9.1	5.06 ± 1.61	15.2 ± 2.5	0.76 ± 0.34	0.93 ± 0.34	3.95 ± 0.74	42.3 ± 6.2	92 ± 15
Treated 'Sugarland'	30.8 ± 9.2	7.33 ± 2.59	10.9 ± 2.7	3.65 ± 0.85	0.85 ± 0.21	3.89 ± 0.85	53.5 ± 6.2	111 ± 18
Treated 'Top Stellina'	26.9 ± 5.2	5.71 ± 1.09	19.1 ± 5.0	6.35 ± 1.46	1.84 ± 0.51	4.88 ± 1.65	61.8 ± 6.3	127 ± 13
HSD interaction	NS	NS	4.1^{***}	NS	NS	NS	5.5^{*}	9^{*}
Treatment × Storage time								
Control S_0	17.7 ± 5.0	5.12 ± 1.33	14.3 ± 4.6	7.60 ± 2.73	1.52 ± 1.03	3.99 ± 2.12	41.6 ± 9.1	92 ± 29
Control S_7	28.0 ± 7.9	10.28 ± 3.87	17.9 ± 4.3	2.21 ± 0.58	1.36 ± 0.61	3.91 ± 1.45	49.5 ± 4.5	113 ± 13
Control S_{14}	23.6 ± 4.8	7.00 ± 1.85	14.1 ± 2.3	1.18 ± 0.49	0.87 ± 0.33	2.98 ± 0.73	41.2 ± 5.8	91 ± 10
Treated S_0	19.3 ± 5.8	4.46 ± 0.96	15.4 ± 7.6	7.18 ± 2.29	1.36 ± 0.86	4.71 ± 1.71	53.0 ± 9.6	105 ± 30
Treated S_7	34.5 ± 7.6	7.50 ± 2.30	14.9 ± 2.0	2.15 ± 0.36	1.21 ± 0.45	4.56 ± 0.63	52.1 ± 9.4	117 ± 16
Treated S_{14}	27.3 ± 6.2	6.14 ± 1.46	15.0 ± 3.9	1.42 ± 0.97	1.06 ± 0.32	3.45 ± 0.55	52.5 ± 8.1	107 ± 13
HSD interaction	NS	NS	2.3^{*}	NS	0.19^{*}	NS	5.5^{*}	NS
Genotype × Storage time								
'Caravaggio' S_0	12.6 ± 2.7	3.68 ± 0.61	11.7 ± 2.6	1.34 ± 0.20	0.68 ± 0.17	3.42 ± 0.55	36.0 ± 5.8	69 ± 9
'Caravaggio' S_7	27.9 ± 7.6	7.61 ± 2.54	19.3 ± 4.2	0.50 ± 0.08	1.37 ± 0.19	4.17 ± 0.70	45.9 ± 7.9	107 ± 13
'Caravaggio' S_{14}	23.2 ± 4.7	6.21 ± 1.63	15.8 ± 2.5	0.30 ± 0.06	0.81 ± 0.20	3.73 ± 0.58	42.6 ± 7.6	93 ± 8
'Sugarland' S_0	21.1 ± 3.9	5.39 ± 0.98	10.8 ± 3.1	6.94 ± 0.84	1.00 ± 0.16	2.93 ± 0.98	44.8 ± 9.3	93 ± 14
'Sugarland' S_7	39.5 ± 6.1	12.43 ± 3.04	15.3 ± 2.9	3.13 ± 1.12	0.66 ± 0.09	4.41 ± 0.68	52.8 ± 6.3	128 ± 8
'Sugarland' S_{14}	27.4 ± 5.8	7.54 ± 2.06	12.0 ± 2.2	1.22 ± 0.47	0.74 ± 0.13	2.91 ± 0.58	47.3 ± 6.1	99 ± 12
'Top Stellina' S_0	21.7 ± 3.3	5.31 ± 1.23	22.0 ± 4.2	13.9 ± 2.35	2.64 ± 0.44	6.71 ± 0.95	61.1 ± 7.3	133 ± 10
'Top Stellina' S_7	26.3 ± 5.4	6.64 ± 0.76	14.5 ± 1.7	2.92 ± 0.55	1.82 ± 0.27	4.12 ± 0.57	53.8 ± 8.1	110 ± 12
'Top Stellina' S_{14}	25.9 ± 6.7	5.96 ± 0.95	15.7 ± 3.3	2.38 ± 0.34	1.36 ± 0.20	3.00 ± 0.60	50.6 ± 9.8	105 ± 19
HSD interaction	7.7^{**}	2.90^{***}	5.0^{***}	1.55^{***}	0.42^{***}	1.32^{***}	9.1^{**}	20^{***}
Overall mean	25.1 ± 8.3	6.75 ± 2.82	15.2 ± 4.5	3.63 ± 1.68	1.23 ± 0.66	3.93 ± 1.30	48.3 ± 10.3	104 ± 21

Note: Each value represents the mean ± standard deviation ($n = 3$). Different letters within the main factors indicate significance at Tukey's HSD test ($P \leq 0.05$). *, ** and ***: significant at $P = 0.05$, 0.01 and 0.001, respectively. NS: not significant.

Table 5 Volatile alcohols and ketones concentration in cherry tomato fruits ($\mu g \cdot kg^{-1}$) as affected by the studied factors

Chemical class	Alcohols			Ketones			
	1-Hexanol	(Z)-3-Hexen-1-ol	Total alcohols	1-Penten-3-one	1-Octen-3-one	6-Methyl-5-hepten-2-one	Total ketones
Source of variation							
Treatment							
Control	15.28 ± 5.98 b	11.84 ± 4.20 b	27.12 ± 11.87 b	6.22 ± 3.81 b	5.36 ± 2.35 a	71.66 ± 17.70 b	137.51 ± 63.75 b
Treated	26.37 ± 9.43 a	16.64 ± 7.26 a	43.01 ± 17.96 a	11.53 ± 6.22 a	5.37 ± 1.72 a	79.05 ± 19.79 a	181.98 ± 89.06 a
Genotype							
'Caravaggio'	14.67 ± 6.50 b	12.02 ± 7.63 b	26.69 ± 11.65 b	3.95 ± 1.08 c	3.96 ± 1.95 c	62.92 ± 21.54 c	124.27 ± 52.3 b
'Sugarland'	41.90 ± 18.19 a	26.98 ± 10.17 a	68.88 ± 21.71 a	7.90 ± 2.25 b	5.37 ± 1.50 b	92.43 ± 16.94 a	243.46 ± 73.74 a
'Top Stellina'	5.90 ± 2.43 c	3.73 ± 1.02 c	9.63 ± 3.60 c	14.77 ± 6.16 a	6.77 ± 1.66 a	70.71 ± 10.77 b	111.51 ± 22.98 b
Storage time							
S_0	32.83 ± 18.93 a	23.22 ± 7.44 a	56.05 ± 17.64 a	13.10 ± 4.50 a	6.46 ± 1.79 a	60.00 ± 16.11 c	191.7 ± 80.88 a
S_7	21.58 ± 12.62 b	11.78 ± 5.07 b	33.36 ± 10.32 b	8.00 ± 3.55 b	5.35 ± 1.11 b	91.24 ± 19.33 a	171.31 ± 92.54 b
S_{14}	8.08 ± 3.01 c	7.72 ± 3.43 c	15.80 ± 6.14 c	5.53 ± 2.15 c	4.29 ± 2.45 b	74.82 ± 14.58 b	116.23 ± 39.81 c
Treatment × Genotype							
Control 'Caravaggio'	10.35 ± 4.77	8.57 ± 9.91	18.92 ± 21.83	3.10 ± 1.83	3.55 ± 2.59	61.25 ± 24.24	105.86 ± 31.19
Control 'Sugarland'	31.78 ± 13.39	23.63 ± 7.69	55.41 ± 20.88	6.82 ± 5.95	6.05 ± 1.49	87.64 ± 19.34	211.33 ± 53.51
Control 'Top Stellina'	3.72 ± 1.09	3.32 ± 0.51	7.03 ± 2.01	8.73 ± 4.23	6.47 ± 1.84	66.08 ± 11.13	95.34 ± 13.69
Treated 'Caravaggio'	19.00 ± 11.11	15.46 ± 18.17	34.46 ± 38.94	4.81 ± 1.6	4.37 ± 0.98	64.59 ± 19.79	142.69 ± 63.85
Treated 'Sugarland'	52.03 ± 21.23	30.32 ± 11.65	82.35 ± 35.94	8.98 ± 4.52	4.69 ± 1.23	97.22 ± 13.56	275.59 ± 79.81
Treated 'Top Stellina'	8.09 ± 3.27	4.14 ± 2.37	12.23 ± 5.08	20.81 ± 6.44	7.07 ± 1.51	75.33 ± 8.64	127.67 ± 20.49
HSD interaction	9.4^{***}	3.2^{*}	10.5^{**}	4.19^{***}	1.32^{**}	NS	NS
Treatment × Storage time							
Control S_0	23.86 ± 11.89	17.23 ± 11.04	41.09 ± 26.09	10.46 ± 5.54	6.47 ± 1.68	53.10 ± 16.22	152.33 ± 58.30
Control S_7	14.68 ± 6.51	11.23 ± 13.59	25.91 ± 33.1	5.83 ± 1.14	5.59 ± 1.31	91.51 ± 16.08	154.74 ± 81.54
Control S_{14}	7.30 ± 2.48	7.06 ± 3.50	14.36 ± 12.89	2.37 ± 2.46	4.01 ± 3.14	70.36 ± 13.24	105.47 ± 37.75
Treated S_0	41.79 ± 16.16	29.21 ± 17.44	71 ± 42.74	15.74 ± 10.36	6.44 ± 2.00	66.89 ± 20.15	231.07 ± 83.74
Treated S_7	28.48 ± 13.12	12.34 ± 15.33	40.82 ± 45.45	10.17 ± 7.31	5.11 ± 0.88	90.97 ± 17.55	187.89 ± 104.55
Treated S_{14}	8.85 ± 3.82	8.38 ± 3.69	17.23 ± 10.00	8.70 ± 4.27	4.57 ± 1.66	79.27 ± 15.24	126.99 ± 41.02
HSD interaction	9.4^{***}	4.6^{**}	13.8^{***}	NS	NS	8.15^{*}	35.89^{***}
Genotype × Storage time							
'Caravaggio' S_0	35.77 ± 12.66	30.29 ± 11.15	66.06 ± 24.25	4.63 ± 2.29	5.13 ± 0.81	39.06 ± 7.49	181.12 ± 49.97
'Caravaggio' S_7	5.72 ± 1.33	2.22 ± 0.65	7.94 ± 4.96	4.36 ± 0.76	4.88 ± 0.95	87.41 ± 7.60	112.54 ± 13.04
'Caravaggio' S_{14}	2.53 ± 0.40	3.54 ± 1.09	6.08 ± 1.28	2.87 ± 1.01	1.86 ± 1.83	62.29 ± 7.70	79.16 ± 12.22
'Sugarland' S_0	54.12 ± 17.22	34.11 ± 9.67	88.23 ± 26.41	14.00 ± 2.7	5.96 ± 1.65	77.28 ± 12.43	273.70 ± 66.29
'Sugarland' S_7	54.24 ± 16.82	30.79 ± 4.62	85.03 ± 20.53	6.46 ± 0.96	5.95 ± 1.30	110.28 ± 8.32	292.75 ± 46.07
'Sugarland' S_{14}	17.35 ± 7.00	16.03 ± 3.85	33.38 ± 4.91	3.25 ± 3.51	4.20 ± 0.87	89.72 ± 9.24	163.93 ± 19.21
'Top Stellina' S_0	8.58 ± 3.04	5.27 ± 1.98	13.85 ± 5.64	20.66 ± 8.82	8.27 ± 1.10	63.65 ± 11.44	120.28 ± 32.01
'Top Stellina' S_7	4.77 ± 2.09	2.34 ± 0.81	7.11 ± 2.34	13.17 ± 7.23	5.22 ± 0.96	76.03 ± 7.04	108.65 ± 16.46
'Top Stellina' S_{14}	4.35 ± 1.10	3.58 ± 0.53	7.94 ± 1.52	10.48 ± 5.44	6.81 ± 1.29	72.44 ± 10.81	105.60 ± 18.87
HSD interaction	11.5^{***}	7.5^{***}	16.9^{***}	5.14^{***}	2.12^{***}	17.69^{***}	43.95^{***}
Overall mean	20.83 ± 12.34	14.24 ± 14.04	35.07 ± 35.81	8.88 ± 7.19	5.36 ± 2.04	75.35 ± 20.90	159.75 ± 79.93

Notes: Each value represents the mean ± standard deviation (n = 3). Different letters within the main factors indicate significance at Tukey's HSD test ($P \leq 0.05$). *, ** and ***: significant at $P = 0.05$, 0.01 and 0.001, respectively. NS: not significant.

Table 6 Other volatiles concentration in cherry tomato fruits (μg · kg^{-1}) as affected by the studied factors

Chemical class	Organic acids			Furans	Thiazoles
	Hexanoic acid	Nonanoic acid	Total organic acids	2-Pentylfuran	2-Isobutylthiazole
Source of variation					
Treatment					
Control	4.46 ± 1.62 a	4.84 ± 2.98 b	9.31 ± 2.79 b	5.69 ± 3.80 b	46.95 ± 13.01 a
Treated	4.80 ± 1.86 a	8.92 ± 5.26 a	13.72 ± 5.82 a	9.71 ± 4.27 a	47.96 ± 16.15 a
Genotype					
'Caravaggio'	4.44 ± 1.51 b	4.62 ± 2.05 b	9.06 ± 2.39 c	8.30 ± 4.39 b	60.39 ± 11.20 a
'Sugarland'	3.66 ± 1.73 c	8.15 ± 4.27 a	11.81 ± 3.23 b	5.21 ± 3.68 c	36.97 ± 11.30 c
'Top Stellina'	5.80 ± 1.25 a	7.87 ± 3.21 a	13.67 ± 7.18 a	9.58 ± 4.41 a	45.01 ± 10.26 b
Storage time					
S_0	4.15 ± 1.92 a	9.95 ± 5.71 a	14.1 ± 7.04 a	4.28 ± 2.12 c	53.95 ± 12.04 a
S_7	4.77 ± 2.00 a	7.11 ± 3.66 b	11.88 ± 3.08 b	8.19 ± 3.56 b	49.34 ± 13.64 a
S_{14}	4.97 ± 1.11 a	3.58 ± 1.26 c	8.56 ± 1.91 c	10.63 ± 3.39 a	39.08 ± 14.32 b
Treatment × Genotype					
Control 'Caravaggio'	4.69 ± 1.94	3.05 ± 1.01	7.74 ± 1.86	6.50 ± 2.70	56.10 ± 9.75
Control 'Sugarland'	3.65 ± 1.65	6.94 ± 3.09	10.59 ± 2.04	4.37 ± 2.91	38.84 ± 12.23
Control 'Top Stellina'	5.05 ± 1.90	4.54 ± 2.10	9.59 ± 3.61	6.19 ± 2.58	45.91 ± 11.66
Treated 'Caravaggio'	4.19 ± 1.08	6.19 ± 1.54	10.38 ± 2.18	10.10 ± 3.41	64.68 ± 11.41
Treated 'Sugarland'	3.66 ± 1.91	9.36 ± 4.08	13.03 ± 3.83	6.05 ± 3.46	35.11 ± 10.69
Treated 'Top Stellina'	6.55 ± 1.11	11.2 ± 5.88	17.75 ± 7.69	12.97 ± 4.94	44.10 ± 9.27
HSD interaction	1.26***	2.66**	3.98***	2.71***	7.33*
Treatment × Storage time					
Control S_0	3.78 ± 1.57	7.24 ± 2.67	11.02 ± 3.29	1.61 ± 0.75	53.57 ± 8.24
Control S_7	5.01 ± 1.98	4.65 ± 2.06	9.66 ± 1.96	7.14 ± 2.42	47.05 ± 13.81
Control S_{14}	4.60 ± 1.09	2.64 ± 0.65	7.24 ± 1.57	8.31 ± 3.85	40.23 ± 13.83
Treated S_0	4.52 ± 2.26	12.67 ± 6.75	17.19 ± 8.54	6.95 ± 3.13	54.32 ± 15.49
Treated S_7	4.53 ± 2.12	9.57 ± 2.35	14.10 ± 2.29	9.24 ± 4.58	51.63 ± 13.88
Treated S_{14}	5.35 ± 1.06	4.52 ± 1.98	9.87 ± 1.20	12.94 ± 4.01	37.94 ± 15.54
HSD interaction	0.71*	1.98*	NS	1.53*	NS
Genotype × Storage time					
'Caravaggio' S_0	3.16 ± 0.49	5.26 ± 1.78	8.42 ± 2.09	3.65 ± 2.05	60.36 ± 9.41
'Caravaggio' S_7	6.05 ± 1.36	4.89 ± 2.65	10.94 ± 1.99	11.40 ± 3.09	65.86 ± 8.62
'Caravaggio' S_{14}	4.09 ± 0.68	3.71 ± 1.59	7.81 ± 2.12	9.85 ± 3.39	54.95 ± 8.55
'Sugarland' S_0	2.74 ± 0.43	10.70 ± 3.99	13.45 ± 4.15	1.39 ± 0.65	45.41 ± 8.32
'Sugarland' S_7	2.36 ± 0.56	10.31 ± 2.33	12.68 ± 2.24	4.84 ± 0.74	41.48 ± 5.99
'Sugarland' S_{14}	5.86 ± 0.92	3.44 ± 0.66	9.30 ± 1.26	9.41 ± 2.13	24.02 ± 4.27
'Top Stellina' S_0	6.55 ± 1.31	13.89 ± 6.78	20.44 ± 7.71	7.79 ± 3.59	56.06 ± 8.57
'Top Stellina' S_7	5.89 ± 1.03	6.12 ± 3.70	12.01 ± 4.63	8.32 ± 3.51	40.67 ± 5.49
'Top Stellina' S_{14}	4.96 ± 1.01	3.60 ± 1.54	8.56 ± 2.25	12.62 ± 3.97	38.28 ± 5.57
HSD interaction	1.54***	4.29***	4.88***	3.32***	12.08**
Overall mean	4.63 ± 1.73	6.88 ± 4.71	11.51 ± 5.04	7.70 ± 4.49	47.46 ± 13.53

Note: Each value represents the mean ± standard deviation ($n = 3$). Different letters within the main factors indicate significance at Tukey's HSD test ($P \leq 0.05$). *, ** and ***: significant at $P = 0.05$, 0.01 and 0.001, respectively. NS: not significant.

significant KH_2PO_4-driven variations in hexanal (279 vs. 703 μg · kg^{-1}, +152%) and (E,E)-2,4-heptadienal (0.44 vs. 0.97 μg · kg^{-1}, +120%) for 'Caravaggio', in hexanal (291 vs. 522 μg · kg^{-1}, +79%), (Z)-3-hexenal (15.5 vs. 29.4 μg · kg^{-1}, +90%), and benzaldehyde (4.79 vs. 6.94 μg · kg^{-1}, +45%) for 'Sugarland', and in (E,E)-2,4-heptadienal (0.46 vs. 0.98 μg · kg^{-1}, +113%) and dodecanal (1.21 vs. 0.84 μg · kg^{-1}, -31%) for 'Top Stellina' (Table 3). Consequently, 'Caravaggio' exhibited the strongest increase in total aldehyde concentration, which passed from 526 (control) to 990 μg · kg^{-1} (treated, +88%) (Table 3). At S_0, control fruits outperformed the treated ones for nonanal concentration (37.0 μg · kg^{-1}) (Table 3). However, passing from S_0 to S_{14}, control fruits exhibited the most marked reduction of hexanal (608 vs. 317 μg · kg^{-1}, -48%), (Z)-3-hexenal (31.2 vs. 17.8 μg · kg^{-1}, -43%), benzaldehyde (2.73 vs. 2.08 μg · kg^{-1}, -24%), heptanal (10.23 vs. 5.64 μg · kg^{-1}, -45%), octanal (11.74 vs. 4.75 μg · kg^{-1}, -60%) and total aldehydes (883 vs. 512 μg · kg^{-1}, -42%) (Table 3). Consequently, treated fruits had a higher total aldehydes concentration than control fruits, particularly at S_7 (1098 vs. 751 μg · kg^{-1}, +46%) and S_{14} (844 vs. 512 μg · kg^{-1}, +65%) (Table 3). The studied cultivars showed differences in relation to the storage time too. Indeed, at S_7, 'Caravaggio' displayed the highest concentrations of decanal, undecanal, and dodecanal (15.30, 3.34, and 0.86 μg · kg^{-1}, respectively), while 'Sugarland' demonstrated the highest contents of pentanal and benzaldehyde (5.47 and 7.72 μg · kg^{-1}, respectively), along with octanal and nonanal (11.59 and 31.90 μg · kg^{-1}, respectively) (Table 3). In contrast, at S_{14}, 'Caravaggio' was the poorest genotype in terms of benzaldehyde and heptanal (1.51 and 4.28 μg · kg^{-1}, respectively), but showed the highest concentrations of undecanal (2.63 μg · kg^{-1}), whereas 'Top Stellina' exhibited the highest contents of pentanal, decanal, and dodecanal (4.84, 11.60, and 1.66 μg · kg^{-1}, respectively), and the lowest concentrations of (Z)-3-hexenal and octanal (13.90 and 4.95 μg · kg^{-1}, respectively) (Table 3).

3.3.2. *Terpene and terpenoid volatiles*

Regardless of the other experimental factors, the preharvest treatment increased the total terpene/terpenoids concentration,

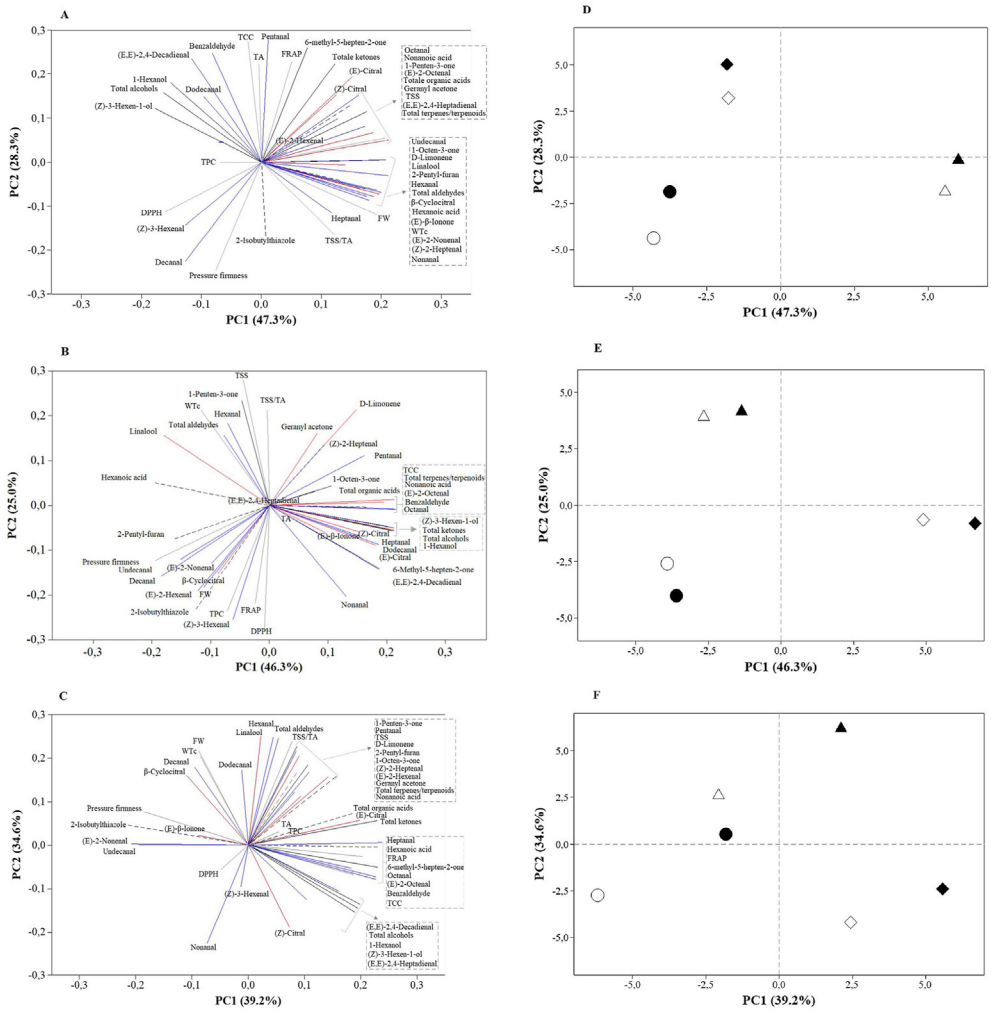


Fig. 2 Principal component analysis (PCA) obtained on the basis of all fruit traits calculated for S_0 (A, D), S_7 (B, E) and S_{14} (C, F)
PCA loadings plot (A, B, C). PCA scores plot (D, E, F). For each loading plot, the variables have been organized into groups of differently colored vectors. Gray: carpometric and functional traits; blue: volatile aldehydes; red: volatile terpenes and terpenoids; black: volatile alcohols and ketones; black dash: other volatiles. In each score plot, circles: 'Caravaggio'; squares: 'Sugarland'; triangles: 'Top Stellina'. White symbols: control fruits; black symbols: treated fruits.

mainly promoting the accumulations of (E)-citral, (E)-β-ionone, and geranylacetone, while simultaneously reducing the concentration of (Z)-citral (Table 4). The significant 'treatment × genotype' interaction revealed a stronger response of 'Top Stellina' to KH_2PO_4 application, mostly for β-cyclocitral, geranylacetone, and total terpenes/terpenoids, reaching 19.1, 61.8, and 127 μg · kg^{-1}, respectively (Table 4). Considering the storage period, the S_7 fruits exhibited the highest concentrations of (E)-citral, (Z)-citral, and total terpene/terpenoid volatiles. Differently, with the exception of geranylacetone, the S_{14} fruits displayed lower concentrations of all terpenes/terpenoids. In this sense, control fruits exhibited the strongest reductions in β-cyclocitral (from 17.9 to 14.1 μg · kg^{-1}, -21%), linalool (from 1.36 to 0.87 μg · kg^{-1}, -36%), and geranylacetone (from 49.5 to 41.2 μg · kg^{-1}, -17%) during the S_7–S_{14} period (Table 4). The 'genotype × storage time' interaction indicated that, passing from S_0 to S_7, 'Caravaggio' and 'Sugarland' exhibited the most marked increases in total terpenes/terpenoids, reaching 107 and 128 μg · kg^{-1}, respectively (Table 4). For 'Caravaggio', this increase was driven by significant rises in (E)-citral (from 12.6 to 27.9 μg · kg^{-1}, +121%), β-cyclocitral (from 11.7 to 19.3 μg · kg^{-1}, +65%), and geranylacetone (from 36.0 to 45.9 μg · kg^{-1}, +28%), while for 'Sugarland', the increase was primarily derived from significant rises in (Z)-citral (from 5.39 to 12.43 μg · kg^{-1}, +131%) and (E)-β-ionone (from 2.93 to 4.41 μg · kg^{-1}, +51%) (Table 4). Differently, between S_7 and S_{14}, this latter genotype showed the steepest depletion of total terpenes/terpenoids (from 128 to 99 μg · kg^{-1}, -23%), mirroring its strongest reductions in (E)-citral (from 39.5 to 27.4 μg · kg^{-1}, -31%), (Z)-citral (from 12.43 to 7.54 μg · kg^{-1}, -39%), and geranylacetone (from 52.8 to 47.3 μg · kg^{-1}, -10%) (Table 4).

3.3.3. *Alcohol and ketone volatiles*

Except for 1-octen-3-one, all alcohol and ketone volatiles, along with their respective total amounts, significantly increased in response to KH_2PO_4 spraying. However, several interactive effects were observed among the main factors (Table 5). Indeed,

comparing control and treated fruits, 'Caravaggio' and 'Sugarland' displayed the most marked increases in 1-hexanol (10.35 vs. 19.00 and 31.78 vs. 52.03 μg · kg^{-1}, respectively), (Z)-3-hexen-1-ol (8.57 vs. 15.46 and 23.63 vs. 30.32 μg · kg^{-1}), and total alcohols (18.92 vs. 34.46 and 55.41 vs. 82.35 μg · kg^{-1}) (Table 5). Contrarily, the latter cultivar showed a significant decrease in 1-octen-3-one (6.05 vs. 4.69 μg · kg^{-1}), while 'Top Stellina' demonstrated the largest increase in 1-penten-3-one (8.73 vs. 20.81 μg · kg^{-1}) (Table 5). Regarding storage time, increased concentrations of all alcohols, 6-methyl-5-hepten-2-one, and total ketones were observed at S_7, while reduced alcohols, 1-penten-3-one and total ketones accumulations emerged at S_{14}. Treated tomatoes exhibited the strongest decreases for 1-hexanol (from 41.79 to 8.85 μg · kg^{-1}, -79%), (Z)-3-hexen-1-ol (29.21–8.38 μg · kg^{-1}, -71%), and total alcohols (71.00–17.23 μg · kg^{-1}, -76%) between S_0 and S_{14} (Table 5). Differently, at S_{14}, control fruits had the least concentrations of 6-methyl-5-hepten-2-one (70.36 μg · kg^{-1}) and total ketones (105.47 μg · kg^{-1}) (Table 5). The 'genotype × storage time' interaction revealed that, at S_7 and S_{14}, 'Sugarland' accumulated higher levels of 1-hexanol (54.24 and 17.35 μg · kg^{-1}, respectively), (Z)-3-hexen-1-ol (30.79 and 16.03 μg · kg^{-1}), total alcohols (85.03 and 33.38 μg · kg^{-1}), 6-methyl-5-hepten-2-one (110.28 and 89.72 μg · kg^{-1}), and total ketones (292.75 and 163.93 μg · kg^{-1}) compared to the other genotypes (Table 5). Conversely, 'Top Stellina' showed the highest concentrations of 1-penten-3-one and 1-octen-3-one at S_{14} (10.48 and 6.81 μg · kg^{-1}, respectively) (Table 5).

3.3.4. *Other volatiles*

The KH_2PO_4 application promoted increases in nonanoic acid, total organic acids, and 2-pentylfuran, with the genotype and storage time modulating most of the responses to the treatment (Table 6). Indeed, in 'Top Stellina', the preharvest treatment elicited the strongest differences compared to control fruits for hexanoic acid (5.05 vs. 6.55 μg · kg^{-1}, +30%), nonanoic acid (4.54 vs. 11.20 μg · kg^{-1}, +147%), total organic acids (9.59 vs. 17.75 μg · kg^{-1}, +85%), and 2-pentylfuran (6.19 vs. 12.97 μg · kg^{-1}, +110%). Differently, 'Caravaggio' showed the most pronounced increase in 2-isobutylthiazole (56.10 vs. 64.68 μg · kg^{-1}, +15%) (Table 6). The significant 'treatment × storage time' interaction revealed that, at S_{14}, treated fruits had higher concentrations of 2-pentylfuran (12.94 vs. 8.31 μg · kg^{-1}) and hexanoic acid (5.35 vs. 4.60 μg · kg^{-1}) compared to control fruits. Additionally, the KH_2PO_4 foliar spray induced higher concentrations of nonanoic acid at S_0 (up to 12.67 μg · kg^{-1}) and S_7 (up to 9.57 μg · kg^{-1}) (Table 6). During storage, the genotypic differences were most pronounced between 'Caravaggio' and 'Sugarland' at S_7 for hexanoic acid (6.05 vs. 2.36 μg · kg^{-1}), nonanoic acid (4.89 vs. 10.31 μg · kg^{-1}), total organic acids (10.94 vs. 12.68 μg · kg^{-1}), and 2-pentylfuran (11.40 vs. 4.84 μg · kg^{-1}), and for 2-isobutylthiazole (54.95 vs. 24.02 μg · kg^{-1}) at S_{14} (Table 6).

3.4. *Principal component analysis*

The scores and loadings plots obtained from the PCA (conducted for S_0, S_7, and S_{14}) are reported in Fig. 2, A–F. Across all storage periods, the first two components showed eigenvalues greater than 1, explaining 75.6% (S_0), 71.3% (S_7), and 73.8% (S_{14}) of the total variance. At S_0, the strongest positive correlations were observed for total terpenes/terpenoids, linalool, and 1-octen-3-one (PC1) and for pentanal, TCC, and 6-methyl-5-hepten-2-one (PC2). Conversely, the correlations were mostly negative for (Z)-3-hexen-1-ol, total alcohols, and DPPH (PC1), as well as for FPF, decanal, and 2-isobutylthiazole (PC2) (Fig. 2, A). For S_7, the correlations were mostly positive for benzaldehyde, (E)-2-octenal, and (Z)-3-hexen-1-ol (PC1), along with TSS, TSS/TA, D-limonene, and 1-penten-3-one (PC2). On the other hand, the strongest negative correlations were observed for hexanoic acid, FPF, and decanal (PC1), and for DPPH, (Z)-3-hexenal, TPC, and 2-isobutylthiazole (PC2) (Fig. 2, B). The PCA conducted for S_{14} revealed strong positive correlations primarily for heptanal, 6-methyl-5-hepten-2-one, and hexanoic acid (PC1), as well as for linalool, hexanal, and total aldehyde volatiles (PC2). Conversely, negative correlations were observed for 2-isobutylthiazole, (E)-2-nonenal, and undecanal (PC1), as well as for nonanal, Z-citral, and (Z)-3-hexen-1-ol (PC2) (Fig. 2, C).

Distinct separations between genotypes, reflecting their volatilome composition, were evident in the score plots. Among the S_0 samples, 'Top Stellina' positioned along the positive side of PC1 due to higher concentrations of terpenoids (particularly linalool, 1-octen-3-one, (E)-β-ionone, and β-cyclocitral), hexanoic acid, and undecanal (Fig. 2, D). Moreover, an evident partitioning between 'Caravaggio' and 'Sugarland' was observed along PC2, with 'Sugarland' exhibiting higher concentrations of aldehydes (primarily pentanal, benzaldehyde, and (E,E)-2,4-decadienal), 6-methyl-5-hepten-2-one, and total terpenes/terpenoids. A similar genotype partitioning was observed at S_7, but with 'Sugarland' staying on the positive side of PC1 due to high fruit concentrations of benzaldehyde, (Z)-3-hexen-1-ol, total alcohol volatiles, and 1-hexanol. Differently, 'Caravaggio' and 'Top Stellina' were separated along PC2, with 'Top Stellina' occupying the positive side of PC2 due to higher fruit concentrations of D-limonene, 1-penten-3-one, hexanal, and linalool (Fig. 2, E). Regarding the S_{14} samples, 'Sugarland' was distinct along both PCs because of its higher concentrations of aldehydes [primarily benzaldehyde and heptanal], alcohols [both 1-hexanol, (Z)-3-hexen-1-ol and their sum] and TCC (along PC1), together with (Z)-3-hexen-1-ol, total alcohols and 1-hexanol (along PC2), whereas a partial overlap was observed between 'Caravaggio' and 'Top Stellina' along PC2 (Fig. 2, F).

For the studied cultivars, at each time point, treated fruits were separated from controls, but this effect was clearer at S_{14}. This response was attributable to the KH_2PO_4-driven increase in aldehyde and ketone volatiles, with prevailing effects from hexanal, octanal, linalool and D-limonene in 'Caravaggio', from (E,E)-2,4,decadienal, hexanal, D-limonene and (E)-β-ionone in 'Sugarland', and from heptanal, (Z)-3-heptenal, geranylacetone and (E)-citral in 'Top Stellina' (Fig. 2, F). Overall, this indicates that both lipid- and carotenoid-derived volatiles are the primary targets of preharvest KH2PO4 application in cherry tomatoes during refrigerated storage.

4. Discussion

4.1. *Carpometric and functional variables*

In this study, after 7 days of storage, cherry tomatoes showed a decreased fresh weight, a feature largely attributable to their transpiration-driven water loss. Consequently, S_7 and S_{14} fruits

were softer than those at S_0, given the close correlation between fruit firmness and tissue water potential (Lester et al., 2010). Averaged over genotypes and storage times, treated tomatoes exhibited the highest fruit pressure firmness, thus demonstrating a positive effect of KH_2PO_4 sprays on a trait linked to tolerance postharvest manipulation (Giuffrida et al., 2018). Similar effects of KH_2PO_4 sprays on tomato have been previously reported as a consequence of the role of K in enhancing the pressure potential within mesocarp tissues (Chapagain and Wiesman, 2004). In contrast, at S_7 and S_{14}, no differences were recorded relative to control fruits, whereas a genotypic differentiation was observed for all of these physical traits. In this sense, our results highlighted the lowest suitability of 'Sugarland' to cold storage because of its highest reductions at S_7 and S_{14} in fruit water content and pressure firmness, thus confirming the central role of the genotype in defining the functional efficiency of the fruit epicarp (Distefano et al., 2020). Accordingly, it has been reported that the dynamics of fruit dehydration and subsequent tissue collapse are conditioned by genotypic differences in cuticle structure, whose alterations over time are intimately linked to the genetically programmed ripening process (Saladié et al., 2007).

In tomato, the TSS/TA ratio represents a proxy of the perceived balance between sweetness (TSS) and sourness (TA) during mastication (Distefano et al., 2022b). In climatic fruits, ethylene-driven ripening and senescence are energy-requiring processes whose temperature-dependent kinetics alter the carbon substrate concentration in the fruit (Anton et al., 2017). During storage, cherry tomatoes showed a decline in TSS and TA, with the decrease in TA being evident as early as S_7. At S_{14}, control fruits showed the strongest reduction in TSS and TSS/TA, thus suggesting a more marked, chill-induced acceleration of their autocatalytic metabolism, which is a common feature among tropical/subtropical fruits subjected to chilling stress (Panigrahi et al., 2017; Albornoz et al., 2022). In this sense, the mildest TSS and TSS/TA reductions in treated fruits suggest a possible regulatory role of KH_2PO_4 in buffering the taste variation of tomatoes during storage. Accordingly, Zahirul et al. (2018) reported reduced respiration rates and energy losses during refrigerated storage in KH_2PO_4 foliar-sprayed cherry tomatoes. On the other hand, under refrigeration, 'Sugarland' exhibited the strongest TA reductions at S_{14}, thus confirming its lowest ability to buffer the chill-induced acceleration of respiratory metabolism. Indeed, it has been reported that organic acids (mainly citrate) have a pivotal role in maintaining high respiratory rates of fruits, even during their postharvest life (Patel et al., 2019; Mauro et al., 2020).

DPPH and FRAP assays are widely used to assess the free radical scavenging activity in vegetables. DPPH activity is based on the stable free radical's ability to decolorize in the presence of antioxidants, while the FRAP assay relies on the reduction of ferric to ferrous ions at low pH, leading to the formation of a colored ferrous-tripyridyltriazine complex (Benzie and Strain, 1999; Patel and Panigrahi, 2019). The preharvest treatment promoted total phenol and carotenoid concentrations, along with the fruits' antioxidant power, as demonstrated by the DPPH and FRAP assays. Accordingly, it has been reported that the growth conditions during cultivation have a central role in determining the antioxidant power of fruit vegetables (Panigrahi et al., 2018). Beyond the genotypic differences, storage at 8 °C promoted total phenols but depressed, in the long term, total carotenoid concentrations, almost mirroring the observed trends in DPPH and FRAP values throughout the storage period. Phenols and carotenoids are prominent plant metabolites that protect cell constituents because of their ROS scavenging activities (Taroncher et al., 2021; Torres-Montilla and Rodriguez-Concepcion, 2021). The increase in phenolic concentrations we observed yet at S_7, is consistent with their known roles in maintaining redoxstasis and in enhancing the thickness of the cell wall, thus preventing membrane peroxidation and tissue collapse under chilling conditions (Sharma et al., 2019). On the other hand, the decreased carotenoid concentration at S_{14} is consistent with the high susceptibility of lycopene (the main carotenoid of red tomatoes) to the chill-induced generation of ROS within the fruit (Distefano et al., 2020). In this experiment, KH_2PO_4 promoted the total carotenoid concentration and FRAP mainly in 'Caravaggio' and 'Top Stellina', respectively, demonstrating a genotype-dependent response to the treatment. However, most importantly, beyond their higher phenolic content, treated fruits exhibited the highest total carotenoids, DPPH and FRAP values, thus highlighting a promoting/protecting role of KH_2PO_4 on the functional traits of cherry tomatoes subjected to cold stress. Accordingly, stimulatory effects of K application on the synthesis of β-carotene (which is less sensitive than lycopene to chill-induced oxidation) have been reported, along with the central role of P-containing metabolites in stimulating the phenolic and isoprenoid pathways (Lester et al., 2010; Martuscelli et al., 2015).

4.2. *Volatile composition*

In this experiment, the detected volatiles were assigned to 7 chemical classes, which were derived from lipids, phenolics, amino acids and carotenoids (Rambla et al., 2014). The KH_2PO_4 application promoted the concentration of 16 out of the 32 volatiles, with more marked effects on aldehydes and apocarotenoids. From a quantitative viewpoint, the 16 aldehydes we identified represented the primary tomato aroma components (~70% of the overall compounds) and were constituted by both saturated and unsaturated volatiles with 5–12 carbon chains. The presence of these compounds is linked to unsaturated membrane lipids, whereas their amounts, which strongly affect tomato flavor, are dictated by the enzymatic activity of lipoxygenase and hydroperoxide lyase and by lipid autoxidation (Viljanen et al., 2011; Farneti et al., 2015). In particular, the activity of lipoxygenase is the most crucial step for their accumulation, as it catalyzes the formation of C_9 and C_{13} hydroperoxides, i.e., the first products of the lipids oxidation process (Wang et al., 2007). The overall aldehyde concentration at S_0 was promoted by KH_2PO_4, with (E,E)-2,4-heptadienal and (E,E)-2,4-decadienal (both derived from linolenic acid), heptanal (derived from (E)-2-octenal) and pentanal (generated by (E)-2-hexenal) (Frankel, 2005; El Hadi et al., 2013) being among the main examples of positive responses to the treatment. A similar effect was recorded for the aldehydes hexanal, (E)-2-hexenal and (Z)-3-hexenal, along with the ketone 1-penten-3-one; due to their positive log odor units, these aldehydes provide primary contributions to tomato aroma (Distefano et al., 2022a). Indeed, when present in proper concentrations, these compounds typically confer fresh/green/fruity/tallow notes

to tomatoes; thus, the KH_2PO_4-induced modifications are expected to generate significant effects on tomato sensory properties. All these compounds are derived from the catabolism of lipid membranes. In particular, hexanal, (E)-2-hexenal and (Z)-3-hexenal arise from lipoxygenase activity on linolenoyl and α-linolenoyl fatty acid groups. During tomato ripening, linoleic and α-linolenic acids can be converted to hexanal and (Z)-3-hexenal, with the latter compound being isomerized to (E)-2-hexenal, thus providing a blend of these C6 aldehydes. The increased levels of these compounds in response to KH_2PO_4 seem consistent with the enhanced concentrations of the alcohols we detected, i.e., 1-hexanol and (Z)-3-hexen-1-ol, which originate from the aldehydes hexanal and (Z)-3-hexenal, respectively (Baenas et al., 2021). Beyond the genotypic differences we recorded, the increases in these compounds upon KH_2PO_4 application can be due to a stimulatory effect of K and P on lipoxygenase activity, which, in turn, is positively correlated with the aldehyde volatiles in the fruit (Wang et al., 2007; Al-Mokadem et al., 2022). Alternatively (or concomitantly), these enhanced concentrations could also be derived from slower ROS-driven degradation of their intact lipid precursors and/or of their promoting enzymes (El Hadi et al., 2013) due to a higher fruit concentration of ROS-scavenging metabolites. Indeed, at the end of storage, 13 out of 16 lipid-derived volatiles proved significant reductions [except for (Z)-2-heptenal, (E)-2-nonenal, and undecanal), with control fruits showing the strongest decreases in total aldehyde volatiles. Only 5 aldehydes ((Z)-3-hexenal, heptanal, (E,E)-2,4-heptadienal, octanal, and nonanal) showed reduced concentrations within the S_0–S_7 period, while the majority of aldehydes depletion [8 out of 13 volatiles, including hexanal and (E)-2-hexenal)] occurred between S_7 and S_{14}. According to Farneti et al. (2015), these reductions are expected to reduce the "freshness" flavor perception deriving from these compounds and, consequently, consumer appreciation for the product. In this framework, both at S_7 and S_{14}, the KH_2PO_4 application enhanced the accumulation of key volatiles in shaping the flavor profile of tomatoes, as in the case of hexanal, (Z)-3-hexenal, benzaldehyde, nonanoic acid, and 2-pentylfuran. On the other hand, it is interesting to note that the KH_2PO_4 treatment enhanced the fruits' phenol and carotenoid concentrations, along with the contents of apocarotenoids, benzaldehyde and 2-pentylfuran, with these last two compounds sharing the same precursor (phenylalanine) with phenylpropanoids (Sharma et al., 2019). Thus, our data suggest an induced protective effect of KH_2PO_4 against non-enzymatic lipids/volatiles peroxidation, which can explain the mildest reductions in some volatile compounds [including hexanal, (Z)-3-hexenal, and (E,E)-2,4-heptadienal] and total aldehydes at S_{14}, i.e., at the end of a time period highly conducive to ROS accumulation within the fruit. This hypothesis seems to be reinforced by the lowest concentration of nonanal observed at S_{14} in treated fruits. Indeed, the genesis of this compound can be traced back to the nonenzymatic oxidation of oleic acid, which, having only 1 double bond, is not a substrate for tomato lipoxygenase activity (Frankel, 2005). Beyond establishing a link between organoleptic and nutraceutical traits, the modifications we observed seem to involve possible food safety aspects of tomato as well, since the stimulatory effects of KH_2PO_4 on volatiles having a role in restricting the postharvest tomato decay e.g. by *Botrytis cinerea* (as for benzaldehyde) or *Salmonella enterica* subsp. *enterica* (as for nonanoic acid) (Finiti et al., 2014; Dev Kumar and Micallef, 2017; Lin et al., 2019).

Apocarotenoid volatiles represents a key class of tomato flavor compounds, conferring floral/fruity notes greatly appreciated by consumers (Distefano et al., 2022a). They are produced by nonenzymatic oxidative cleavage of several linear and cyclic carotenoids or by a family of carotenoid cleavage dioxygenases (Wang et al., 2016). In our experiment, these volatiles were represented by 7 terpenes/terpenoids along with the ketone 6-methyl-5-hepten-2-one. The KH_2PO_4 treatments increased the concentrations of 4 main apocarotenoids, i.e., (E)-citral (also known as neral, derived from carotenoids), (E)-β-ionone (derived from β-carotene), geranylacetone (derived from phytoene, phytofluene, ζ-carotene or neurosporene) and 6-methyl-5-hepten-2-one (derived from lycopene), which are all generated by oxidative cleavage of their corresponding precursors (Wang et al., 2016; Tieman et al., 2017; Distefano et al., 2022a). When considering the postharvest trends of the apocarotenoids, the concentrations of some pivotal compounds (i.e., (E)-citral, (Z)-citral, and 6-methyl-5-hepten-2-one) peaked at S_7, while all their corresponding concentrations were lower at S_{14}, except for geranylacetone. In this regard, it is noteworthy that the observed parallel decline in fruit concentrations of carotenoids and most apocarotenoids, passing from S_7 to S_{14}, corroborates the idea of a quantitative relationship existing between apocarotenoids and their isoprenoid precursors (Tieman et al., 2017). However, compared to the control, S_{14} treated fruits showed higher concentrations of 3 compounds affecting both primary (6-methyl-5-hepten-2-one) and secondary (linalool and geranylacetone) tomato flavor notes (Distefano et al., 2022a). These differences could have further significant implications from a sensory perspective for cold-stored cherry tomatoes, as apocarotenoid volatiles, beyond their effect on fruits' olfactory bouquets, can also significantly impact the perceived tomato sweetness during mastication (Tieman et al., 2017).

Regarding the cultivars, the responses of carotenoid-derived volatiles to either KH_2PO_4 or storage time were often genotype-dependent. When considering the genotypic differences over the entire storage period, at S_{14} there were divergent responses among 'Caravaggio' (showing the lowest concentrations of D-limonene and linalool), 'Sugarland' (which outperformed the other genotypes in terms of 6-methyl-5-hepten-2-one), and 'Top Stellina' (displaying the highest levels of D-limonene and linalool). These divergences suggest a higher proneness of 'Caravaggio' to apocarotenoid depletion and flavor alteration during refrigerated storage. On the other hand, 'Top Stellina' displayed the highest responsiveness to the KH_2PO_4 treatment because of its strongest increase in terms of β-cyclocitral, geranylacetone and total terpenes/terpenoids; overall, this highlights the central role of the genetic background in the flavor reconfiguration of KH_2PO_4-treated cherry tomatoes subjected to refrigerated storage.

5. Conclusions

The current results demonstrate the possibility of modulating multiple quality traits of cherry tomatoes through preharvest KH_2PO_4 foliar sprays, along with their postharvest behavior in response to refrigerated storage. From a carpometric and functional viewpoint, the effects were positive for FPF, TSS, TA, total

phenol and carotenoid contents, and fruit antioxidant capacity, along with the fruits' ability to buffer the detrimental effects of chilling storage (up to 14 days at 8 °C) on TSS, TSS/TA, carotenoid concentration, DPPH and FRAP. This has important implications from the perspective of preserving pivotal functional and sensory traits of cherry tomatoes along the distribution chain. Moreover, preharvest KH_2PO_4 application enhanced the fruit concentrations of 16 of the 32 odor-active compounds considered in this study. Beyond the genotypic differences we observed, some of these modifications were still relevant at the end of the storage period, particularly for some important odor-active aldehydes [e.g. hexanal, (Z)-3-hexenal, benzaldehyde and total aldehydes) and apocarotenoids (linalool, geranylacetone and 6-methyl-5-hepten-2-one], along with nonanoic acid and 2-pentylfuran. The properties of these volatiles indicate a possible role of KH_2PO_4 in extending the persistence of fresh/fruity/floral perceptions in cold-stored cherry tomatoes, with possible positive effects on consumers' acceptance. We are aware that, without a reliable sensory evaluation, the real organoleptic impact of our findings remains elusive, since tomato flavor derives from complex interactions among a multitude of volatile and nonvolatile compounds. Nonetheless, given the experimental evidence, the present study can represent a step toward the agronomic optimization of KH_2PO_4 utilization (e.g., concentration, time of application) to preserve specific commercial, nutritional and organoleptic traits of cherry tomatoes along the geographical and temporal path linking production and consumption.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The study was partially funded by the National Recovery and Resilience Plan (NRRP), Mission 4 Component 2 Investment 1.3—Call for proposals No. 341 of 15 March 2022 of Italian Ministry of University and Research funded by the European Union—NextGenerationEU, Award Number: Project code PE00000003, Concession Decree No. 1550 of 11 October 2022 adopted by the Italian Ministry of University and Research, CUP E63C22002060006, Project title "ON Foods—Research and innovation network on food and nutrition Sustainability, Safety and Security—Working ON Foods. The study was also partially funded by the Italian Ministry of University and Research (MUR) under the project "Conservabilità, qualità e sicurezza dei prodotti ortofrutticoli ad alto contenuto di servizio - ARS01_00640 – POFACS" (Grant Nos. D.D. 1211/2020 and 1104/2021).

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at https://doi.org/10.1016/j.hpj.2023.12.016.

REFERENCES

Ahn, T., Oke, M., Schofield, A., Paliyath, G., 2005. Effects of phosphorus fertilizer supplementation on antioxidant enzyme activities in tomato fruits. J Agric Food Chem, 53: 1539–1545.

Al-Mokadem, A.Z., Alnaggar, A.E.A.M., Mancy, A.G., Sofy, A.R., Sofy, M.R., Mohamed, A.K.S.H., Abou Ghazala, M.M.A., El-Zabalawy, K.M., Salem, N.F.G., Elnosary, M.E., Agha, M.S., 2022. Foliar application of chitosan and phosphorus alleviate the Potato Virus Y-induced resistance by modulation of the reactive oxygen species, antioxidant defense system activity and gene expression in potato. Agronomy, 12: 3064.

Albornoz, K., Zhou, J., Yu, J., Beckles, D.M., 2022. Dissecting postharvest chilling injury through biotechnology. Curr Opin Biotechnol, 78: 102790.

Anton, D., Bender, I., Kaart, T., Roasto, M., Heinonen, M., Luik, A., Püssa, T., 2017. Changes in polyphenols contents and antioxidant capacities of organically and conventionally cultivated tomato (*Solanum lycopersicum* L.) fruits during ripening. Int J Anal Chem, 2017: 6–10.

Baenas, N., Bravo, S., García-Alonso, F.J., Gil, J.V., Periago, M.J., 2021. Changes in volatile compounds, flavour-related enzymes and lycopene in a refrigerated tomato juice during processing and storage. Eur Food Res Tech, 247: 975–984.

Benzie, I.F.F., Strain, J.J., 1999. Ferric reducing/antioxidant power assay: Direct measure of total antioxidant activity of biological fluids and modified version for simultaneous measurement of total antioxidant power and ascorbic acid concentration. Methods Enzymol, 299: 15–27.

Boon, J.K., 2020. Global trade in fresh fruit increased by 2 million tonnes per year in the past 10 years [WWW Document]. URL. https://www.freshplaza.com/article/2189566/global-trade-in-fresh-fruit-increased-by-2-million-tonnes-per-year-in-the-past-10-years/.

Brand-Williams, W., Cuvelier, M.E., Berset, C., 1995. Use of a free radical method to evaluate antioxidant activity. LWT–Food Sci Technol, 28: 25–30.

Brückner, B., Auerswald, H., 2019. Instrumental data - consumer acceptance. In: Shewfelt, R.L., Brückner, B. (Eds.), Fruit & Vegetable Quality - an Integrated View. CRC Press, Boca Raton, pp. 178–198.

Castello, I., D'Emilio, A., Raviv, M., Vitale, A., 2017. Soil solarization as a sustainable solution to control tomato Pseudomonads infections in greenhouses. Agron Sustain Dev, 37: 1–10.

Chapagain, B.P., Wiesman, Z., 2004. Effect of Nutri-Vant-PeaK foliar spray on plant development, yield, and fruit quality in greenhouse tomatoes. Sci Hortic, 102: 177–188.

Constán-Aguilar, C., Leyva, R., Blasco, B., Sánchez-Rodríguez, E., Soriano, T., Ruiz, J.M., 2014a. Biofortification with potassium: antioxidant responses during postharvest of cherry tomato fruits in cold storage. Acta Physiol Plant, 36: 283–293.

Constán-Aguilar, C., Leyva, R., Romero, L., Soriano, T., Ruiz, J.M., 2014b. Implication of potassium on the quality of cherry tomato fruits after postharvest during cold storage. Int J Food Sci Nutr, 65: 203–211.

Daoud, B., Pawelzik, E., Naumann, M., Li, Z., Qiu, Q., Chen, Y., Lin, D., Huang, J., Huang, T., Avani, P., Bauri, F.K., Sarkar, S.K., Zahirul, I.M., Young-Tack, L., Akter, M.M., Ho-Min, K., 2018. Different potassium fertilization levels influence water-use efficiency, yield, and fruit quality attributes of cocktail tomato—a comparative study of deficient-to-excessive supply. Plant Physiol Biochem, 272: 234–243.

Dev Kumar, G., Micallef, S.A., 2017. Susceptibility of Salmonella enterica isolates from tomato farm environments to fatty acids naturally found on tomato fruit. Foodb Pathog Dis, 14: 293–301.

Distefano, M., Arena, E., Mauro, R.P., Brighina, S., Leonardi, C., Fallico, B., Giuffrida, F., 2020. Effects of genotype, storage temperature and time on quality and compositional traits of cherry tomato. Foods, 9: 1729.

Distefano, M., Mauro, R.P., Page, D., Giuffrida, F., Bertin, N., Leonardi, C., 2022a. Aroma volatiles in tomato fruits: the role of genetic, preharvest and postharvest factors. Agronomy, 12: 376.

Distefano, M., Steingass, C.B., Leonardi, C., Giuffrida, F., Schweiggert, R., Mauro, R.P., 2022b. Effects of a plant-derived biostimulant application on quality and functional traits of greenhouse cherry tomato cultivars. Food Res Int, 157: 111218.

El Hadi, M.A.M., Zhang, F.J., Wu, F.F., Zhou, C.H., Tao, J., 2013. Advances in fruit aroma volatile research. Molecules, 18: 8200–8229.

Faostat, 2022. Crops and livestock products [WWW Document]. URL. https://www.fao.org/faostat/en/#data/QCL.

Farneti, B., Alarcón, A.A., Papasotiriou, F.G., Samudrala, D., Cristescu, S.M., Costa, G., Harren, F.J.M., Woltering, E.J., 2015. Chilling-induced changes in aroma volatile profiles in tomato. Food Bioprocess Technol, 8: 1442–1454.

Finiti, I., de la, O., Leyva, M., Vicedo, B., Gómez-Pastor, R., López-Cruz, J., García-Agustín, P., Real, M.D., González-Bosch, C., 2014. Hexanoic acid protects tomato plants against *Botrytis cinerea* by priming defence responses and reducing oxidative stress. Mol Plant Pathol, 15: 550–562.

Frankel, E.N., 2005. Lipid Oxidation, Second. Woodhead Publishing Limited, Sawston, Cambridge (UK).

Gautier, H., Diakou-Verdin, V., Bénard, C., Reich, M., Buret, M., Bourgaud, F., Poëssel, J.L., Caris-Veyrat, C., Génard, M., 2008. How does tomato quality (sugar, acid, and nutritional quality) vary with ripening stage, temperature, and irradiance? J Agric Food Chem, 56: 1241–1250.

Giuffrida, F., Agnello, M., Mauro, R.P., Ferrante, A., Leonardi, C., 2018. Cultivation under salt stress conditions influences postharvest quality and glucosinolates content of fresh-cut cauliflower. Sci Hortic, 236: 166–174.

Klee, H.J., 2010. Improving the flavor of fresh fruits: genomics, biochemistry, and biotechnology. New Phytol, 187: 44–56.

Klee, H.J., Tieman, D.M., 2013. Genetic challenges of flavor improvement in tomato. Trends Genet, 29: 257–262.

Lester, G.E., Jifon, J.L., Makus, D.J., 2010. Impact of potassium nutrition on postharvest fruit quality: melon (*Cucumis melo* L.) case study. Plant Soil, 335: 117–131.

Li, Z., Qiu, Q., Chen, Y., Lin, D., Huang, J., Huang, T., 2021. Metabolite alteration in response to low phosphorus stress in developing tomato fruits. Plant Physiol Biochem, 159: 234–243.

Lichtenthaler, H.K., Buschmann, C., 2001. Chlorophylls and carotenoids: measurement and characterization by UV-VIS spectroscopy. Curr. Protoc. Food Anal Chem, 1 (F4.3.1-F4.3.8).

Lichtenthaler, H.K., Wellburn, A.R., 1983. Chlorophyll and carotenoid determination. Biochem Soc Trans, 603: 591–592.

Lin, Yongwen, Ruan, H., Akutse, K.S., Lai, B., Lin, Yizhang, Hou, Y., Zhong, F., 2019. Ethylene and benzaldehyde emitted from postharvest tomatoes inhibit *Botrytis cinerea* via binding to G-protein coupled receptors and transmitting with cAMP-signal pathway of the fungus. J Agric Food Chem, 6: 13706–13717.

Martuscelli, M., Di Mattia, C., Stagnari, F., Speca, S., Pisante, M., Mastrocola, D., 2015. Influence of phosphorus management on melon (*Cucumis melo* L.) fruit quality. J Sci Food Agric, 96: 2715–2722.

Mauro, R.P., Agnello, M., Onofri, A., Leonardi, C., Giuffrida, F., 2020. Scion and rootstock differently influence growth, yield and quality characteristics of cherry tomato. Plants, 9: 1725.

Panigrahi, J., Gheewala, B., Patel, M., Patel, N., Gantait, S., 2017. Gibberellic acid coating: a novel approach to expand the shelf-life in green chilli (*Capsicum annuum* L.). Sci Hortic, 225: 581–588.

Panigrahi, J., Patel, M., Patel, N., Gheewala, B., Gantait, S., 2018. Changes in antioxidant and biochemical activities in castor oil-coated *Capsicum annuum* L. during postharvest storage. 3 Biotech, 8: 1–8.

Parisi, M., Pentangelo, A., D'Alessandro, A., Festa, G., Francese, G., Navarro, A., Sanajà, V.O., Mennella, G., 2023. Grafting effects on bioactive compounds, chemical and agronomic traits of 'Corbarino' tomato grown under greenhouse healthy conditions. Hortic Plant J, 9: 273–284.

Patel, C., Panigrahi, J., 2019. Starch glucose coating-induced postharvest shelf-life extension of cucumber. Food Chem, 288: 208–214.

Patel, N., Gantait, S., Panigrahi, J., 2019. Extension of postharvest shelf-life in green bell pepper (*Capsicum annuum* L.) using exogenous application of polyamines (spermidine and putrescine). Food Chem, 275: 681–687.

Petró-Turza, M., 1986. Flavor of tomato and tomato products. Food Rev Int, 2: 309–351.

Rambla, J.L., Tikunov, Y.M., Monforte, A.J., Bovy, A.G., Granell, A., 2014. The expanded tomato fruit volatile landscape. J Exp Bot, 65: 4613–4623.

Saladié, M., Matas, A.J., Isaacson, T., Jenks, M.A., Goodwin, S.M., Niklas, K.J., Xiaolin, R., Labavitch, J.M., Shackel, K.A., Fernie, A.R., Lytovchenko, A., O'Neill, M.A., Watkins, C.B., Rose, J.K.C., 2007. A reevaluation of the key factors that influence tomato fruit softening and integrity. Plant Physio, 144: 1012–1028.

Sharma, A., Shahzad, B., Rehman, A., Bhardwaj, R., Landi, M., Zheng, B., 2019. Response of phenylpropanoid pathway and the role of polyphenols in plants under abiotic stress. Molecules, 24: 1–22.

Taroncher, M., Vila-Donat, P., Tolosa, J., Ruiz, M.J., Rodríguez-Carrasco, Y., 2021. Biological activity and toxicity of plant nutraceuticals: an overview. Curr Opin Food Sci, 42: 113–118.

Teerachaichayut, S., Ho, H.T., 2017. Non-destructive prediction of total soluble solids, titratable acidity and maturity index of limes by near infrared hyperspectral imaging. Postharvest Biol Technol, 133: 20–25.

Tieman, D., Zhu, G., Resende, M.F.R., Lin, T., Nguyen, C., Bies, D., Rambla, J.L., Beltran, K.S.O., Taylor, M., Zhang, B., Ikeda, H., Liu, Z., Fisher, J., Zemach, I., Monforte, A., Zamir, D., Granell, A., Kirst, M., Huang, S., Klee, H., 2017. A chemical genetic roadmap to improved tomato flavor. Science, 355: 391–394.

Torres-Montilla, S., Rodriguez-Concepcion, M., 2021. Making extra room for carotenoids in plant cells: new opportunities for biofortification. Prog Lipid Res, 84: 101128.

Viljanen, K., Lille, M., Heiniö, R.L., Buchert, J., 2011. Effect of high-pressure processing on volatile composition and odour of cherry tomato purée. Food Chem, 129: 1759–1765.

Wang, F.T., Liu, J.L., Xu, K.F., Ai, X.Z., 2007. Effect of potassium on flavor quality and LOX activity of cucumber in solar-greenhouse. Acta Hortic, 761: 463–470.

Wang, L., Baldwin, E.A., Bai, J., 2016. Recent advance in aromatic volatile research in tomato fruit: the metabolisms and regulations. Food Bioprocess Technol, 9: 203–216.

Zahirul, I.M., Young-Tack, L., Akter, M.M., Ho-Min, K., 2018. Effect of pre-harvest potassium foliar spray and postharvest storage methods on quality and shelf life of cherry tomatoes. Res J Biotechnol, 13: 49–54.

Zhou, Z., Yuan, Y., Wang, K., Wang, H., Huang, J., Yu, H., Cui, X., 2022. Rootstock-scion interactions affect fruit flavor in grafted tomato. Hortic Plant J, 8: 499–510.