Reducing the carbon emissions from Qianxi tomato fruits preservation by cold atmospheric plasma

Tao Jin[1,2], Yan Chen[2], Chenwei Dai[3], Jimin Deng[4], Qinghua Xu[3*], Zhengwei Wu[1,2,5*]

(1. *School of Nuclear Science and Technology, University of Science and Technology of China, Hefei 230026, China*;
2. *Joint Laboratory of Plasma Application Technology, Institute of Advanced Technology, University of Science and Technology of China, Hefei 230031, China*;
3. *Anhui Academy of Medical Sciences, Hefei 230061, China*;
4. *Anhui Institute for Food and Drug Control, Hefei 230051, China*;
5. *CAS Key Laboratory of Geospace Environment, University of Science and Technology of China, Hefei 230026, China*)

Abstract: China has pledged to reach its dual-carbon goals (i.e., carbon peak and carbon neutrality) at the end of 2060. To reduce carbon emission in food preservation industry, the preservation effects of cold atmospheric plasma intermittent treatment (1 min/6 h each day, PL4) combined with 15°C and 4°C only on Qianxi tomato fruits during 7 d storage were investigated. Results indicated that the firmness, *L**, sensory taste, glutathione (GSH) content, mineral (Fe, P, K) content, polyphenol oxidase activity of PL4 tomatoes were significantly increased than that in Control during earlier period storage, with worse weight loss, titratable acid, *a**, *b**, lycopene content, ·OH radical scavenging capacity and same moisture content, total soluble solids, polysaccharide content, total phenolics content, total flavonoid content, ascorbic acid content, 1,1-diphenyl-2-picrylhydrazyl radical scavenging capacity, pectin methylesterase activity. Moreover, the power and R134a consumption of PL4 were highly decreased by around 56.4 kW·h and 0.3 g respectively during whole storage as compared to Control, and reduced more than 99.8% carbon emission based on equipment using stage. All in all, this study illustrated that PL4 treatment can be applied as an ecofriendly, low carbon and sustainable preservation strategy for short-term storage of fruits under 4°C or higher temperature.

Keywords: cold atmospheric plasma, carbon reduction, Qianxi tomato fruits, food preservation
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1 Introduction

Climate warming has become the biggest concern in the world and a large amount of greenhouse gases emissions including CO_2, CH_4, N_2O, HFCs, PFCs, SF_6 and NF_3 are evaluated as the main cause. China's carbon emission surpassed the US as the top CO_2 emitter since 2005 and contributed to approximately 1/3 of the global carbon emission in 2021[1]. As the second largest economic entity and biggest developing country in the world, China has the responsibilities and obligations to reduce the carbon emission and protect ecological environment. Chinese president Xi Jinping pledged in the 75th Session of the United Nations General Assembly on September 22, 2020, that China will reach carbon peak before 2030 and carbon neutrality until 2060[2].

4°C household refrigerator is recommended to preserve nearly all daily fresh products' qualities including nutrients, taste, aroma and appearance. However, different fruits, vegetables and meats have their own optimal storage temperature and relative humidity[3]. Food products stored at 4°C also taste bad without direct and obvious sweet, acid, etc., due to ice feeling. The weather surveys of ten cities of Anhui province in 2021 showed that the daily average temperature lower/equal to 15℃ exceed 140 d [4]. Thus, a higher temperature such as 12°C-14°C (apples, pears, kiwi, peaches, nectarines) or 17°C (bananas, pineapple, mango, melon, tomatoes) may be an alternative choice for food preservation[3]. Higher storage temperature (>4°C) does have the advantage that reducing the temperature fluctuation, which can decrease quality and weight loss during door opening and power failure of household refrigerator[5]. But it faces an urgent challenge that how to meet the similar preservation effect as 4°C household refrigerator. Though there are numerous literatures reporting that melatonin, hexanal, ethyl pyruvate, even leaf extracts solutions, and lights (X-ray, γ-ray, blue light, UV) can present significantly preservation effects on preventing/retarding fungal decay and maintenance overall quality of fresh fruits[6-11]. Most of them are difficult to conduct in household refrigerator or need extra time to clean food products' surface. Thus, an ecofriendly, effective, safe and lower energy consumption method like cold atmospheric plasma is suggested as a better choice.

"Cold atmospheric plasma" is described as a kind of complex system contains electrons, molecules, free radicals, UV and so on. In recent decades, corona discharge, pulsed corona discharge, glow

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Biographies: Tao Jin, PhD candidate, research interest: plasma physics, cold atmospheric plasma application, food preservation, Email: tonnyhellotonny@163.com; **Yan Chen**, MS candidate, research interest: microbiology, plasma medicine, Email: chenyann@mail.ustc.edu.cn; **Chenwei Dai**, MS, research interest: identification of pathogenic microorganisms, disinfection technology, Email: 87358066@qq.com; **Jimin Deng**, MD, research interest: quality of traditional Chinese medicine, Email: 531339878@qq.com.
***Corresponding author: Qinghua Xu**, Chief Physician of Public Health, research interest: disinfection technology, nosocomial infection control. Anhui Provincial Center for Disease Control and Prevention, Hefei 230601, China. Tel: +86-551-62825823, Email: xqh1126@sina.com; **Zhengwei Wu**, PhD, Professor, research interest: plasma physics, materials science and engineering. School of Nuclear Science and Technology, University of Science and Technology of China, Hefei 230026, China. Tel: +86-551-63606045, Email: wuzw@ustc.edu.cn.

discharge, radiofrequency (RF) discharge, microwave discharge, plasma jet and dielectric barrier (DBD) discharge are the main discharge modes to produce nonthermal/cold plasma. While DBD and jet are the two popular devices operated in researched literatures due to their simple design and reconfiguration possibilities to accommodate many types of targets and treatment requirements[12]. Through selectively comparing the data mentioned in previous literatures, some meaningful conclusions are obtained. Won et al.[13] investigated nitrogen-cold plasma treatment (900 W, 10 min) during 5 d storage at 25°C displayed lower CO_2 generation, similar Hue angle, total soluble solids contents, titratable acidity and ascorbic acid concentration on mandarin as compared to 4°C. Zhou et al.[14] applied air-surface plasma discharge (30, 60, 90, 120 s) to treat fresh-cut apple accompanied by storing at room temperature showed minimal differences on weight loss, firmness, PPO and POD activities as compared to refrigeration-stored (4°C). Min et al., also used atmospheric cold plasma treatment (35 kV, 1.1 A, 3 min) combined with 25°C displayed similar firmness, lycopene content, residual ascorbic acid concentration, L^*, a^* and b^* values of grape tomatoes as compared to control storage at 10°C only[15].

According to the comparison and analysis above, the study aimed to apply DBD plasma intermittent treatment (1 min/6 h at every day) combined with 15°C to preserve Qianxi tomato fruits for 7 d. The power consumption, carbon emission, physicochemical parameters, nutrients qualities and enzyme activities were studied as compared to that storage at 4°C only.

2 Materials and methods

2.1 Sample preparation

500 Qianxi tomatoes (bred by a Chinese enterprises) with same size and maturity (red stage), and without any destroy and decay were purchased from a local fruits store. Within 30 min, all tomatoes were shifted to the Lab (15°C) and immediately immersed in 200 μL/L sodium hypochlorite solution for 3 min to eliminate microbials and dust. Extra ultrapure water was used to washed residual sodium hypochlorite on tomatoes surface. Finally, the tomatoes were provisionally stored at 4°C for late use.

2.2 Experimental design

The DBD plasma device produced by epoxy resin and copper was presented in Figure 1, of whose low voltage electrode (copper bar) was sticked on the board and high voltage electrode (copper sheet) was encapsulated in the board. The discharge area was 10 cm×15 cm and ambient air was used as the working gas. A time switch was used to turn on/off DBD when treated tomatoes. Besides, a digital oscilloscope with current and voltage probes was employed to monitor the U-I waveforms during gas discharge.

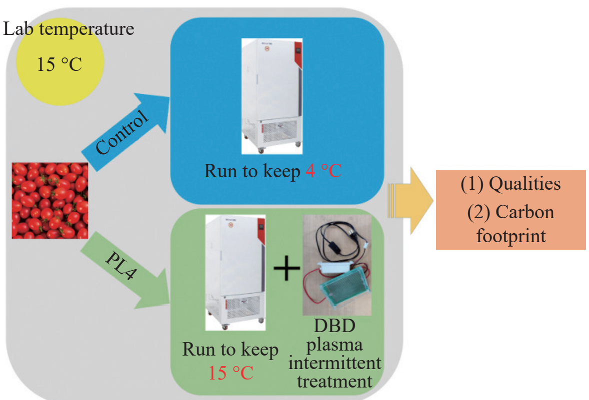


Figure 1 The experimental flow diagram

Based on the results of preliminary experiments, an optimized experimental design was decided that using DBD plasma to treat tomatoes at a distance of 20 cm for 1 min/6 h under 15°C during 7 d storage (coded as PL4). The tomatoes without DBD treatment were stored at 4°C only and abbreviated as Control. It should be pointed out that two same incubators (Volume: 100 L, Refrigerant Charge: 200 g R134a) contain 250 tomatoes each were put in a constant temperature Lab (at 15°C), and one was set 4°C for Control to simulate household refrigerator environment and another was set 15°C for PL4 to serve as the Lab temperature. The weight loss, moisture content, firmness, total soluble solids (TSS), titratable acid (TA), sensory evaluation and color of tomato samples were characterized at day 0, 1, 3, 5 and 7. At each sampling day, 25 tomatoes were cut, ground by liquid nitrogen and stored at –80°C for late determinations.

2.3 Carbon emission assessment

To compare the carbon emission of two preservation strategies, the power consumption was recorded by an electric energy monitor (High Education Research Technology Co., Ltd, Beijing, China, accuracy: 0.1 kW·h). Clearly, the value of Control is equal to the power consumption of the incubator to keep 4°C under 15°C environment during 7 d storage. The value of PL4 is amount to the power consumption of DBD discharge only during the whole storage. The R134a consumption and carbon emission of two preservation methods were evaluated by SGS-CSTC Standards Technical Services Co., Ltd (SGS Company, Shanghai, China).

2.4 Weight loss, moisture content, firmness, TSS, TA, L^*, a^*, b^* and sensory evaluation

The weight loss (%) was averaged by ten tomatoes and measured at day 0, 1, 3, 5 and 7. The accurate value was calculated by the equation below,

$$\text{Weight loss}\ (\%) = \frac{M_0 - M_s}{M_0} \times 100 \tag{1}$$

where, M_0 and M_s represent the weight (g) of samples at day 0 and sampling days (s = 1, 3, 5 and 7), respectively.

Moisture content was determined by the Chinese standard (GB 5009.3-2016) with some modifications. Glass petri dish contained minced tomato samples were hot air-dried at 105°C for 2 h. After cooling for 30 min, the weight was recorded and kept dried again until the final weight was 50 mg less than last weight. The moisture content was obtained by the equation below,

$$\text{Moisture content}\ (\%) = \frac{M_0 - M_f}{M_0} \times 100 \tag{2}$$

where, M_0 and M_f represent the origin and final weight (g) of tomato sample, respectively.

Firmness assay was carried out on a texture analyzer (TA-XTPLUS, STABLE) with P/2N probe. The test speed and penetrate distance were 5 mm/s and 10 mm, respectively. Three points of each sample were test and averaged as one data. The final value was averaged by five tomatoes and recorded as N.

Total soluble solids (TSS) was determined by measuring the refractive index with a hand-held sugar meter (LB32T, Guangzhou, China). Tomatoes with 15 mL ultrapure water were homogenized for 90 s. The filtrate obtained by four layers absorbent cotton was pour into 25 mL volumetric flask and 100 μL mixture was dropped in sugar meter and the value was recorded. The final TSS was calculated by the following equation,

$$\text{Total soluble solids}\ (\%) = P \cdot \frac{M + 15}{M} \times 100 \tag{3}$$

where, P and M are the accurate number on the sugar meter and sample's weight, respectively.

Extra water was added into the 25 mL volumetric flask till to the scale line. Taken out 5 mL mixture to another 25 mL beaker and added 10 mL water. The titratable acid (TA) was determined by a titrator (Mettler Toledo) using 0.18 M sodium hydroxide (calibrated) until pH 7.8 was reached (GB/T 12456-2008). The TA value was calculated by the equation below and averaged by five tomatoes and expressed as g citric acid/kg on a fresh weight basis,

$$\text{Titratable acid (g/kg)} = \frac{c \cdot V \cdot K \cdot \mathrm{F}}{M} \times 1000 \tag{4}$$

where, c and V are the concentration (0.18 M) and used volume (mL) of sodium hydroxide respectively; K is the acid conversion factor (citric acid as 0.064); F is the dilution times; M is the initial weight of tomatoes, g.

The color parameters are main including L^*, a^* and b^* values which L^* for lightness: from 0-black to 100-white, a^* for red-green: from –120-green to 120-red, and b^* for yellow-blue: from –120-blue to 120-yellow, respectively. The L^*, a^* and b^* values were quantitatively analyzed using a colorimeter (WSC-S, Shanghai, China). After continuously calibrated by whiteboard and blackboard, the color data were obtained and averaged by the same ten tomato samples as weight loss assay.

Sensory analysis was conducted by nine trained volunteers. The assessment consisted of asking panelists to mark the intensity of color, smell, taste and texture on 27 tomato slices which ranging from 1-extremetly dislike to 5-extremely like. Spring water was used for rinsing and paper towels for leaning the mouth between assessments. These assessed attributes were found adequate to describe quality changes of tomatoes during storage.

2.5 Polysaccharide, total phenolics, total flavonoid, lycopene, glutathione, ascorbic acid and mineral (Fe, P, K) content

The polysaccharide and glutathione (GSH) content were determined according to the protocols of detection kits (Solarbio, Shanghai, China), respectively. The results were averaged by three replicates and final values were recorded as mg/g and μg/g respectively on a fresh weight basis.

According to the previous literatures and with some adjustments, the total phenolics (TPC), total flavonoid (TFC), lycopene and ascorbic acid (AsA) content were determined[16,17]. The TPC and TFC values of tomatoes were calculated from standard curves obtained with gallic acid and rutin, and expressed as μg GAE/g and μg RE/g, respectively.

1.0 g tomatoes with 4 mL ultrapure water were ground and centrifuged at 10 000 g and 4°C for 10 min. 3 mL supernatant was analyzed by inductively coupled plasma optic emissions spectrometer (ICP-OES, Opmita 7300 DV) and the main mineral including iron (Fe), phosphorus (P) and potassium (K) in tomatoes were converted and recorded as μg/g.

2.6 DPPH and ·OH radical scavenging capacity, hydrogen peroxide content

According to Li et al. [17], with some modifications, the DPPH and ·OH radical scavenging capacity of tomatoes were determined by using the residue extract solution of TPC and TFC assays at the same day. The results were both recorded as %/g.

Besides, the hydrogen peroxide (H_2O_2) contents in tomatoes were measured by detection kit (Solarbio, Shanghai, China) using UV spectrophotometry. According to the instructions of kit, the final reaction solution was detected at 415 nm and the results were recorded as μmol/g.

2.7 Enzyme activities of pectin methylesterase and polyphenol oxidase

The pectin methylesterase (PME) and polyphenol oxidase (PPO) activities were assayed by the Elisa kits (Liborui, Wuhan, China), respectively. The OD values were both obtained at 450 nm and the results were recorded as U/kg on a fresh weight basis.

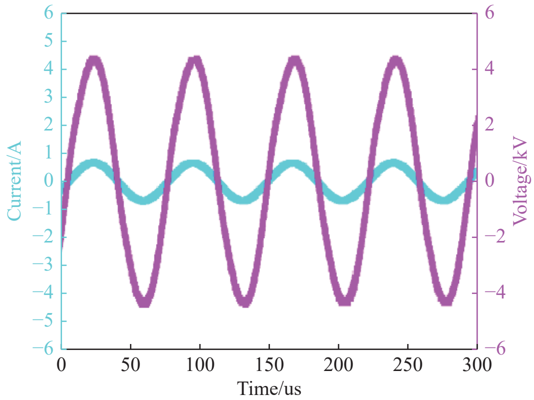
2.8 Statistical analysis

All experiments were carried out for at least three replicates. The experimental data were calculated by Excel and results were expressed as the mean ± standard deviation (Std). All figures were plotted by Origin 8.5 and combined by Adobe Illustrator 2020. Statistically significant differences between Control with PL4 was conducted by t-test, while p<0.05, 0.01 and 0.001 represent significant, extremely significant and highly significant differences, respectively.

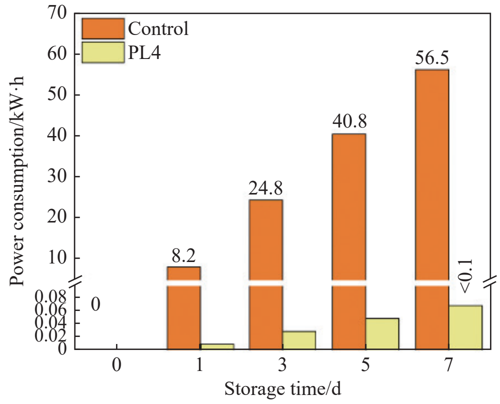
3 Results and discussion

3.1 U-I curves and carbon emission

As shown in Figure 2, DBD plasma device has a discharge frequency of 14.04 kHz. The peak-to-peak voltage and current were 8.80 kV and 1.42 A, respectively. For power consumption, the value of Control was 56.5 kW·h at the end of storage, which was higher than that of PL4. According to SGS company' assessment, the R134a consumption was reduced by 0.3 g, the carbon emission of Control and PL4 were 59.7 kg CO_2-eq and 0.1 kg CO_2-eq respectively, which reduced by more than 99.8 % carbon emission based on equipment using stage. Thus, PL4 treatment can be applied as a low carbon and energy-saving preservation strategy for short-time storage of tomato fruits.



a. Waveforms of applied voltage and current

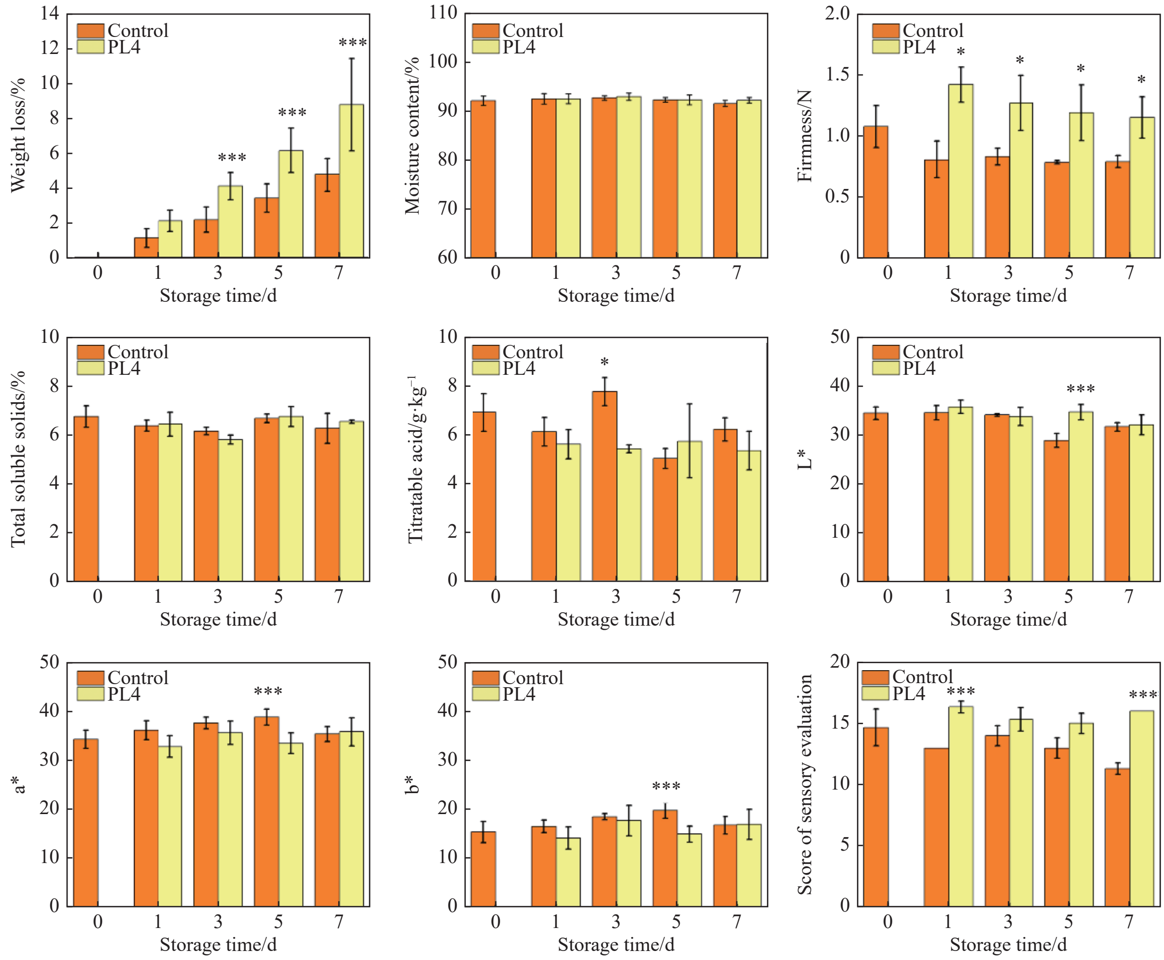


b. Power consumption

Figure 2 Waveforms of applied voltage and current of DBD plasma device and power consumption of Control and PL4 during 7 d storage

3.2 Weight loss, moisture content, firmness, TSS, TA, *L**, *a**, *b** and sensory evaluation

To further verify and prove that PL4 can be an alternative solution of traditional household refrigerator (4°C), the physicochemical qualities, nutrients contents, antioxidant properties and enzyme activities of PL4 treated tomatoes were fully determined as compared to Control. It is known that cold plasma mostly increases the weight loss of fruits through reducing water content and affecting respiration rate. However, as shown in Figure 3, the weight loss of Control and PL4 were gradually increased with the prolonger storage and the PL4 tomatoes have larger weight loss at day 3, 5 and 7 (***p<0.001) as compared to Control. Differently, Figure 3 displayed no significant difference of moisture content between Control with PL4. This maybe because the nature relative humidity in the incubator under 4°C and 15°C were enough for the water exchange of tomatoes within 7 d storage, which is correlated with the previous research[18]. Furthermore, Giannoglou et al.[19] also pointed that short time cold plasma treatment to strawberry can accelerate cell metabolism and respiration so that lead to larger weight loss.



Note: * and *** indicate differences of p<0.05 and p<0.001 between Control with PL4 at the same day, respectively.

Figure 3 The weight loss, moisture content, firmness, total soluble solids, titratable acid, *L**, *a**, *b** and score of sensory evaluation of Control and PL4 tomatoes at day 0, 1, 3, 5 and 7

Figure 3 showed the firmness of tomatoes in PL4 were further increased as compared to Control at day 1, 3, 5 and 7 (*p<0.05). It noticeable that PL4 treatment leaded a maximum improvement in firmness of tomatoes at first day, then the difference values of firmness between Control with PL4 were slowly reduced till the end of storage, which indicated that the effects of cold plasma exposure on texture and relevant enzymes of tomato fruits were short and can be adapted and decrease soon. A similar finding has been reported that cold plasma treatment for 5 min can increase the firmness of blueberries during 10 d storage though displayed no significant difference[20]. Gavahian et al., also indicated that DBD plasma treatment for 20 min can significantly increase the firmness of fresh shiitake mushrooms at day 7[21].

TSS is one of the weightiest quality criteria used to represent the sweetness of fresh and processed horticultural food products, and mainly consists of organic acids, soluble amino acids, fats, minerals, alcohol and flavonoids[22]. As shown in Figure 3, the TSS content of PL4 tomatoes had no significant difference as compared to Control during 7 d storage. The result was agreement with Liao et al.[23], who explained the reason may be due to brief exposure treatment is not enough for the active species produced by cold plasma to reach macromolecules of tomatoes. Consequently, the TSS in tomatoes remained unaffected.

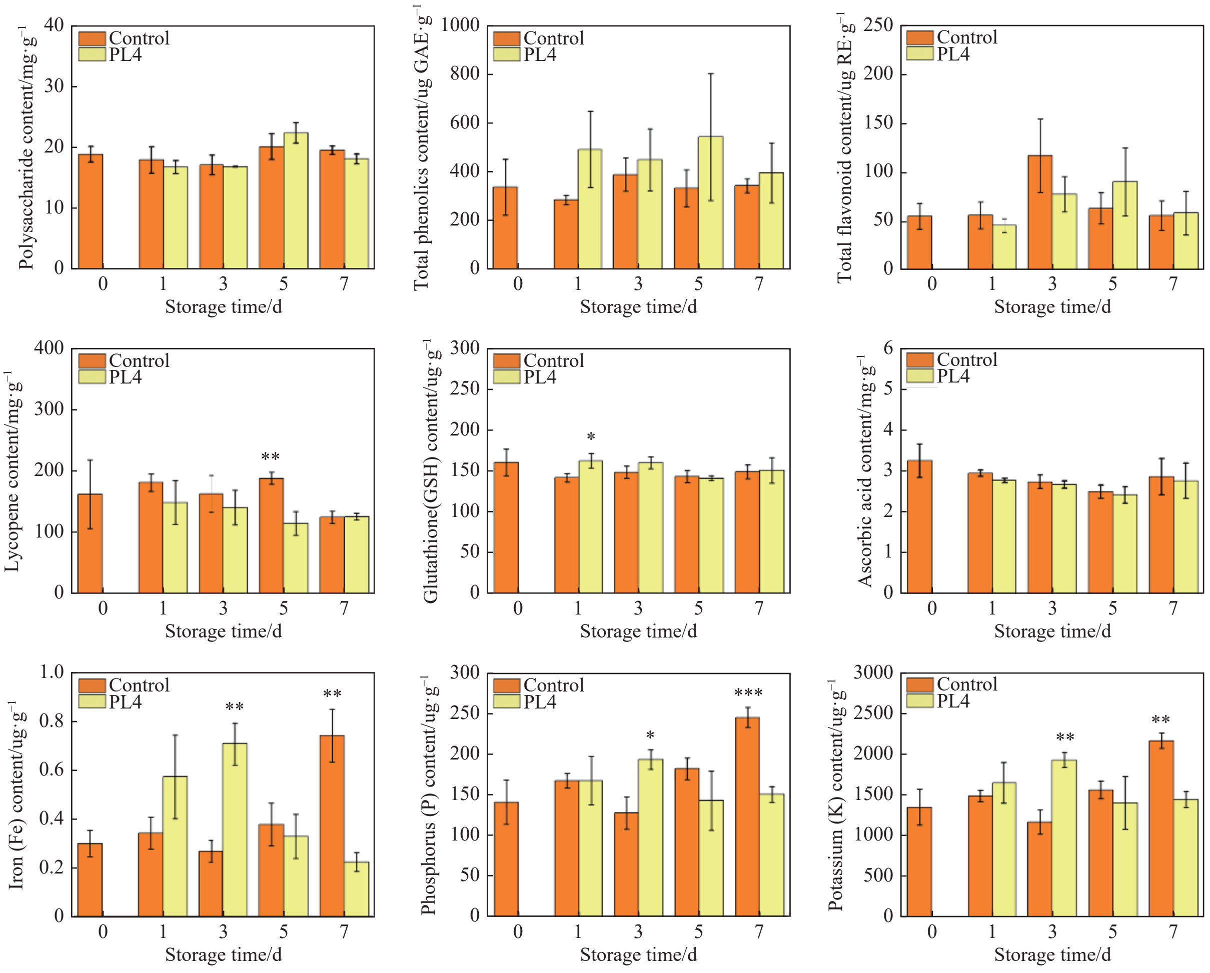
Acidity is a qualitative feature in food products and titratable acidity is an estimate of the total amount of acids in food and the concentrations of hydrogen ions[24]. Though the TA content of Control tomatoes was higher than that in PL4 at day 3 (*p<0.05), the values of that at day 1, 5 and 7 were no significant differences. Misra explained this may be due to the buffering action, the physiological activity of living tissues and the possibility of fluid leaving the damaged tissues on the surface and washing the surface acids[25]. Moreover, Won et al.[13] also investigated cold plasma treatment for 10 min at 25°C during 7 d storage did not affect the TA content of mandarin as compared to 4°C only.

The color of fresh food products is highly related to endogenous pigments, which can be degraded or oxidized by the cold plasma treatment. Furthermore, the pigment retention might be attributed to relevant enzyme denaturation[26]. As shown in Figure 3, PL4 tomatoes were glossier (L^*) than Control (***p<0.001), but a^* and b^* values of Control were larger than PL4 (***p<0.001) at day 5. Moreover, the L^*, a^* and b^* values of Control and PL4 have no significant differences at day 1, 3 and 7. The finding was similar to that of Danijela et al.[27], who indicated cold plasma has barely noticeable color difference of pomegranate juice. Baier et al.[28] also presented that cold plasma treatment for 30 s at 5 mm distance lead no pronounced leaf color changes.

According to Figure 3, the score of sensory evaluation of PL4 was greater than Control at day 1 and 7. This may lead to the higher firmness and good brittleness of PL4 tomatoes as compared to Control. On the other hand, negative sour taste related to TA content and faint color directly affected the score of Control tomatoes.

3.3 Polysaccharide, TPC, TFC, lycopene, GSH, AsA and mineral (Fe, P, K) content

Polysaccharide are biomolecules consists of carbon, oxygen and hydrogen atoms that are found in a wide variety of food products. Many studies showed that cold plasma can influence the swelling capacity, thermal characteristics, pasting properties, solubility, viscosity, crystallinity, structure and digestibility of polysaccharide through depolymerization, crosslinking, formation of new functional groups, changing the hydrophilic nature, etching of granules and degradation of starch molecules[29,30]. Nevertheless, the result showed that the polysaccharide content of PL4 tomatoes has no significant difference as compared to that of Control at day 1, 3, 5 and 7 (Figure 4). This may be due to intermittent cold plasma treatment for 1 min/6 h just led to little effects on the extract efficiency of polysaccharide and did not change its structure.



Note: *, ** and *** indicate differences of p<0.05, p<0.01 and p<0.001 between Control with PL4 at the same day, respectively.

Figure 4 The polysaccharide content, total phenolics content, total flavonoid content, lycopene content, glutathione content, ascorbic acid content, Fe, P and K content of Control and PL4 tomatoes at day 0, 1, 3, 5 and 7

Figure 4 showed no noticeable differences in total phenolics (TPC), total flavonoid (TFC) and lycopene content of PL4 tomatoes as compared to Control, but the lycopene value of Control tomatoes was higher than that in PL4 at day 5 (**p<0.01). Sruthi et al., summarized that cold plasma treatment can degrade phenolic compounds through generating ozone and other reactive species. On the other hand, an increment of phenolic content can be accredited to the activation of phenylalanine ammonia-lyase (PAL), one of the crucial enzymes in synthesizing phenolic compounds[31]. Thus, the decreasing effects of PL4 treatment maybe equal to the increasing effects on TPC and TFC of tomatoes in this study. Differently, the reactive oxygen species (ROS) produced by PL4 treatment might be reacted with lycopene so that reducing its content at day 5.

As shown in Figure 4, the glutathione (GSH) and ascorbic acid

(AsA), common non-enzymatic antioxidants, were neither no significant difference between PL4 with Control. However, the GSH content of PL4 tomatoes was larger than Control at day 1 (*p<0.05). Chen et al., explained that AsA-GSH cycle, the powerful abiotic stress defense systems in plants, not only directly removed a range of ROS but also participated in many other functions to keep the cell in a favorable state[32]. Thus, the GSH content of PL4 tomatoes could be improved under oxidative stress by short cold plasma treatment. The result was similar to Misra et al., who reported that cold plasma treatment at a voltage of 60 kV showed stable ascorbic acid and anthocyanin content of strawberries[33]. Puligundla et al.[34,35] also pointed that intermittent plasma treatment showed no significant changes in the total phenolic content, lycopene and ascorbic acid of in-packaged cherry tomatoes and kumquats.

To adequately compare the preservation effects of PL4 to traditional method (Control) on tomatoes, the main mineral including Fe, P and K were stated in Figure 4, H and I, respectively. It can be seen that three mineral contents of Control tomatoes were stable before 3 d and then start increased, while of that in PL4 were firstly increased and subsequently reduced. As a result, the Fe, P and K content of PL4 were all larger than that in Control at day 3 (**p<0.01, *p<0.05, **p<0.01, respectively), but lower than that in Control at day 7 (**p<0.01, ***p<0.001, **p<0.01, respectively). According to Matan et al.[36] and Sarangapani et al.[37], the reason of mineral content increment in tomatoes maybe due to the improvement of its extract rate under PL4 treatment. However, the cause why trace mineral decrease is unclear.

3.4 DPPH and ·OH radical scavenging capacity, H_2O_2 content

The antioxidant property of food products is depended on the type and content of antioxidants including phenolic acids, flavonoids, polysaccharide, and so on. In this study, the antioxidant activities of tomatoes were characterized by DPPH and ·OH radical scavenging capacity. As shown in Table 1, the DPPH radical scavenging capacity of PL4 tomatoes has no significant difference as compared to that in Control during whole storage. The result was agreement with Puligundal et al.[35], who reported intermittent cold plasma treatment can preserve the antioxidant compounds in kumquat and present the same DPPH radical scavenging capacity as compared to control within 10 d. The ·OH radical scavenging capacity of PL4 tomatoes was stable during 7 d storage and close to the value of that at day 0. However, the value of that in PL4 was lower than Control at day 5 and 7 (*p<0.05). According to previous literatures, this may be due to PL4 treatment can produce extra ·OH radical so that increased the initial ·OH radical level and gradually reach maximum at alter period storage[38].

Table 1 DPPH and ·OH radical scavenging capacity, and H_2O_2 content of Control and PL4 tomatoes at day 0, 1, 3, 5 and 7

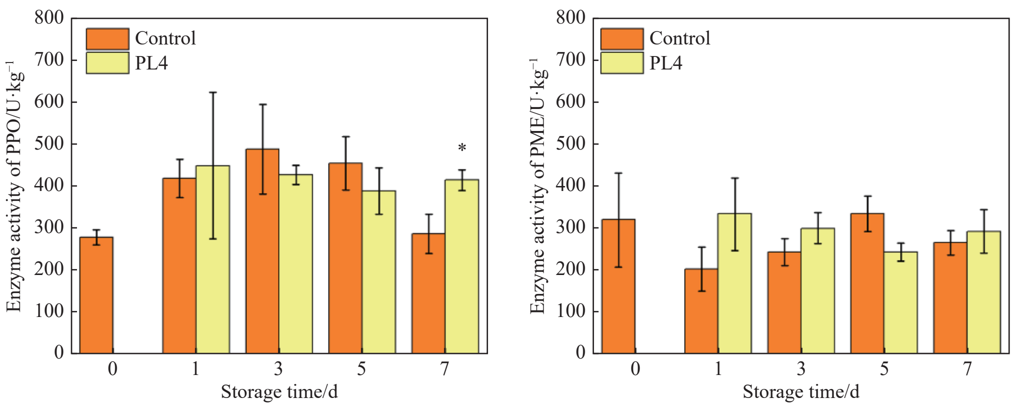
		Day 0	Day 1	Day 3	Day 5	Day 7
DPPH radical scavenging capacity/%·g^{-1}	Control	111.18±32.61	87.10±12.12	118.77±15.44	68.03±19.18	86.01±19.33
	PL4		82.00±16.28	103.94±14.58	96.73±6.95	73.76±3.47
·OH radical scavenging capacity/%·g^{-1}	Control	126.63±17.72	113.95±13.98	121.28±26.84	190.77±40.74*	167.68±22.93*
	PL4		93.73±31.53	103.85±21.66	90.87±26.26	80.66±28.72
H_2O_2/μmol·g^{-1}	Control	2.79±0.65	4.24±0.53	3.43±0.12**	3.85±0.54	3.22±0.22
	PL4		3.94±0.51	2.65±0.08	2.92±0.30	3.35±0.48

Note: Results are expressed as the means ± standard error. Means with * and ** indicate different significance levels of p<0.05 and p<0.01 between Control with PL4 at the same day, respectively.

The ROS level of tomatoes was represented by hydrogen peroxide (H_2O_2) content. The H_2O_2 content of PL4 and Control tomatoes were both increased at day 1 and then decreased from day 3 to day 7. The H_2O_2 content of PL4 displayed no significant difference as compared to Control at day 1, 5 and 7, but lower than that at day 3 (**p<0.01). Based on the results of Wang et al.[39], the lower H_2O_2 content of PL4 tomatoes at day 3 maybe because intermittent cold plasma treatment enhanced antioxidases' activity including catalase (CAT), superoxide dismutase (SOD) and peroxidase (POD) so that degraded H_2O_2 into water and oxygen molecules.

3.5 PME and PPO activities

The PPO and PME activities are mostly related to the fruits color and maturity. As shown in Figure 5, PL4 treatment can both maintain the PPO and PME activities of tomatoes, while of that in Control were firstly increased and then reduced during 7 d storage. The PPO activity of Control tomatoes was lower than that in PL4 at day 7 (*p<0.05), which maybe due to PL4 treatment enhanced phenylalanine metabolism to resisted oxidative stress, so that accelerated the biosynthesis of oxidases, phenolics and flavonoids



Note: * indicate differences of p<0.05 between Control with PL4 at the same day.

Figure 5 PME and PPO activities of Control and PL4 tomatoes at day 0, 1, 3, 5 and 7 compounds[31]. PME is a ubiquitous cell wall bound enzyme which plays an important role in ripening fruits and affects the shelf life of fresh produce. However, literature about inactivation of PME by cold plasma treatment is extremely limited[40].

4 Conclusions

This study successfully demonstrates the feasibility of cold atmospheric plasma intermittent treatment combined with 15°C ambient temperature for the effective preservation of Qianxi tomato fruits and contributes to the fundamental understanding of cold atmospheric plasma on the postharvest qualities of Qianxi tomato fruits. The moisture content, TSS, polysaccharide content, TPC, TFC, AsA, DPPH radical scavenging capacity and PME activity of PL4 tomatoes has no significant differences as compared with that in Control during the 7 d storage. Though the TA (difference at day 3), *a** (day 5), *b** (day 5), lycopene content (day 5), ·OH radical scavenging capacity (day 5, 7) and H_2O_2 content (day 3) of Control tomatoes were higher than that in PL4 at several days during whole storage, the weight loss (day 3, 4, 5), Firmness (day 1,3, 5, 7), *L** (day 5), sensory assessment (day 1, 7), GSH content (day 1), PPO activity (day 7) of PL4 were all larger than that in Control. Besides, PL4 can effectively reduce about 0.3 g R134a use and 56.4 kW·h power consumption, which decrease more than 99.8% carbon emission based on equipment using stage as compared to Control. Taken together, cold atmospheric plasma intermittent treatment (1 min/6 h each day) at 15°C surrounding environment hold the similar preservation effects as compared to 4°C refrigerator during a short-term storage of Qianxi tomato fruits.

In this work, all findings proposed that temperature above 4°C such as 15°C maybe more suitable for many short-term storage fruits and vegetables, which still presents same preservation effects as 4°C only. Moreover, the 4°C-higher temperature, with low energy and refrigerant consumption, and less carbon emission, can be easily obtained by the ambient temperature (winter and autumn) or new-design refrigerator.

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