Photosensitisation combined with ozone gas delays the postharvest ripening of stored tomato

Sayali More and T.V. Ramana Rao*

P.G. Department of Biosciences,
Sardar Patel University,
Vallabh Vidyanagar-388 120, Gujarat, India
Email: sayali.more0588@gmail.com
Email: tadapanenirao@yahoo.com
*Corresponding author

Abstract: Tomato faces pathogen attack which is a major cause of postharvest losses. The present study is carried out to minimise its postharvest losses and to extend its shelf life by physical elicitors such as photosensitisation, ozone and UV-C. The quality of the fruit was evaluated by the quantitative analysis of physico-chemical, biochemical and enzymatic assay at a regular interval of 5 d during storage. The results showed significantly higher levels of total phenols, ascorbic acid, carotene, lycopene and the antioxidant activity throughout their storage as compared to control. The fruits of T5 group (photosensitisation and ozone gas treatment) remained marketable up to 40 d, while the non-treated fruits were acceptable up to 22 d. The nutritional quality of stored tomato was also found better in treated fruit than control. These results suggest that the photosensitisation and ozone is found effective in the postharvest extension of tomato and maintaining their nutritional quality.

Keywords: ozone gas; photosensitisation; shelf life; tomato; UV-C irradiation.

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Biographical notes: Sayali More is a doctoral research student of Biosciences Department of Sardar Patel University, Gujarat state, India. Her research is mainly focused on the optimisation and evaluation of safe post-harvest technologies for improvement of shelf-life and quality maintenance of some short-lived tropical fruits. She presented her work at various national and international conferences.

T.V. Ramana Rao is a Professor of Botany in the Biosciences Department of Sardar Patel University, Gujarat. India. His major areas of research interest are postharvest physiology of fresh and minimally processed fruits and vegetables with major emphasis on the improvement of health promoting properties and shelf life extension. He has published several research articles in refereed national and international journals. He is a recipient of several awards and fellowship of national and international repute.

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1 Introduction

Tomato (*Solanum lycopersicum*) belongs to the family Solanaceae is the most important commercial crop in the world and also it is a climacteric fruit which is prone to several postharvest diseases due to pathogens (Kimura and Sinha, 2008). India stands second to China in the production of tomato with 11% of global production. As per horticulture statistics at a glance 2018, India produces 19,759 thousand MT of tomatoes in which Madhya Pradesh and Andhra Pradesh are the leading states for producing tomatoes and 12.44% of total production of tomatoes get rotten. Tomatoes are not only the source of variety of nutrients but are also having health promoting antioxidants like lycopene and carotenoid (Arab and Steck, 2000). Aidoo et al. (2014) attributed the economic loss of tomato cultivation to the post-harvest losses. These losses are due to the diseases and short storage life has become global concern since it causes massive loss of horticultural yield; approximately 25% of fruits are spoiled due to postharvest diseases (Ahmed et al., 2017).

Tomato is susceptible to multiple bacterial, fungal, viral and pathogens which ultimately results in postharvest losses (Martínez-Castro et al., 2018). To overcome this problem various chemicals and fungicides are being used but these chemicals are harmful for human consumption and it has overreached for research efforts using other safe eco-friendly alternatives (Tusiime, 2014).

Photosensitisation is a novel disinfection technique involving the use of photoactive component (sodium chlorophyllin) and LED lights. The exposure of fruits to LED lights triggers ample of phototoxic reactions and eventually kill the surface microorganisms (Paskeviciute and Luksiene, 2009). Another technique involves ozone as a potent disinfecting agent. As an oxidising agent in organic reaction, ozone is used in many food industries (Pandiselvam et al., 2017). Ultraviolet-C (UV-C) irradiation treatment has been successfully applied on a wide range of fresh produce including climacteric and non-climacteric fruits and the beneficial effects of UV-C hormesis include pathogen resistance, delayed chlorophyll degradation and improved nutritional content (Scott et al., 2018). Therefore, the current study has been focused on surface sterilisation by non-thermal disinfection techniques like photosensitisation, ozone treatment and UV-C irradiation.

2 Material and methods

Tomato fruit cv. 'Himsona' was harvested at their physiological maturity from the farm located in the vicinity of Bakrol village, Anand district of Gujarat, India. Tomatoes were transported to the research laboratory within one hour of harvesting. Fruits selected were free from any kind of visible defect and injuries.

The elicitor treatments applied on the tomato fruits are as follows:

T1 Photosensitisation alone

T2 UV-C (20 min) alone

T3 Ozone gas (200 mg/h for 30 min) alone

T4 Photosensitisation and UV-C

T5 Photosensitisation and ozone gas

T6 UV-C and ozone gas

T7 Ozone gas, UV-C and photosensitisation, C-Control (washed with water).

2.1 Application of the treatments

The method followed for application of this treatment was described by Luksiene and Paskeviciute (2011). Tomatoes were soaked in 1 mM sodium chlorophyllin solution for five minutes and then air dried. The dried tomatoes were placed in treatment chamber and they were exposed to LED light at wavelength of 400 nm for 20 min. After application of the tomatoes were stored in controlled atmosphere, i.e., 25°C and 50% RH.

Ozone treatment was applied on tomato fruits by keeping them in a container and covered with aluminium foil. The probe of the ozoniser (Kent ozoniner) was inserted through the aluminium foil for proper contact between ozone gas and fruit surface.

2.2 Determination of weight loss percentage

The electronic weighing scale (Essae DS-252) was used to weigh fresh tomatoes and during the treatment and study intervals. The weight loss during storage time was expressed in percentage using following formula given in the standard method of AOAC (1994).

$$W(\%) = W_i - W_t / W_i * 100$$

$W - PLW$, W_i – Initial weight of fruit

W_t – Weight during storage.

2.3 Estimation of pH and total soluble solids

The digital pH metre (EI, 101) was used to measure pH and hand refractometer (Atago, Japan) was used to record the total soluble solid (TSS). The sample was prepared by crushing 1 g of fruit tissue with 10 mL of distilled water. The results were calculated using standard method given in AOAC (1994).

2.4 Determination of total phenolic content and total antioxidant activity

The total phenolic content in the methanolic extract of tomato (1 g of tomato tissue crushed in 10 mL of methanol) was estimated by Folin-Ciocalteu reagent method (McDonald et al., 2001). The total phenolic content of the extract was calculated using Gallic acid as a standard and expressed as g kg^{-1}.

DPPH (Diphenyl-2-picrylhydrazyl) free radical scavenging assay was performed for determining antioxidant activity. DPPH solution was prepared by dissolving DPPH powder (0.06 g L^{-1}) in methanol and for estimation of antioxidant activity, this solution was added to supernatant which was extracted by crushing of 1 g of fruit tissue in 10 mL of methanol. The reaction mixture was made up to 3 mL and the absorbance of the sample was measured at wavelength of 517 nm after incubating samples in the dark for 30 min (Brand-Williams et al., 1995).

2.5 Determination of ascorbic acid

Ascorbic acid (Vitamin C) content was estimated by the method of Kapur et al. (2012) with a slight modification. The extract prepared by crushing 1 g of fruit tissue in 10 mL of 6% of meta-phosphoric acid and 2 M glacial acetic acid. The aliquot (0.2 mL) volume was up to 1 mL by 6% of meta-phosphoric acid and 2 M glacial acetic acid and then mixed with 1 mL of 2% di-nitrophenyl hydrazine (DNPH) and 30 µL of 10% thiourea and incubated at room temperature for 3 h. 5 mL of 85% cold sulphuric acid was then added to terminate the reaction and absorbance was recorded at wavelength of 540 nm and expressed as 10g kg^{-1}.

2.6 Determination of the lycopene and carotene pigments

Lycopene and carotene pigments were extracted from tomato fruit tissue (1 g) with 10 mL of hexane: acetone (60:40). Absorbance was measured by using UV-VIS spectrophotometer at wavelength of 502 and 450 nm respectively against reagent blank and it was expressed as mg kg^{-1} (Wang et al., 2007).

2.7 Assay of the antioxidant enzyme

Superoxide dismutase (SOD) was performed by observing the nitro-blue tetrazolium (NBT) reduction by the method described by Cao et al. (2007). 5 g of tissue was homogenised with 10 mL of extraction buffer (50 mM sodium phosphate buffer, pH 7.5 and 1% PVP). The activity was assayed by making 3 mL of reaction mixture (0.1 mL enzyme extract, 75 µM of NBT, and 20 µM of riboflavin, 0.1 mM EDTA, 13 mM methionine and 50 mM potassium phosphate buffer, pH 7.8). One set of reaction mixture was exposed to 4000 lx light and the other set was kept in dark for 20 min. One unit of SOD activity expressed as the amount of enzyme required to inhibit the 50% of NBT reduction at wavelength of 560 nm and expressed as U mg^{-1} protein (Cao et al., 2007).

2.8 Determination of cell wall degrading enzyme

Extraction and assay of polygalacturonase (PG) enzyme was carried out by following the method described by Srivastava and Dwivedi, (2000). One gram of tomato tissue was homogenised with 10 mL of 20 mM sodium phosphate buffer, pH 7.0. The extract was centrifuged at 4 °C for 30 min. The supernatant was used as an aliquot and the reaction mixture was containing sodium acetate buffer (200 mM), Sodium chloride (200 mM), polygalacturonic acid (1%). The enzyme activity was expressed as U mg^{-1} protein.

2.9 Estimation of protein

Protein content was estimated by following the method described by Lowry et al. (1951) for calculating the specific activity of enzymes.

2.10 Statistical analysis

The data obtained from all the experiments carried out in triplicate was analysed by using SPSS software. Mean comparisons were performed using HSD of Tukey's test, Duncan

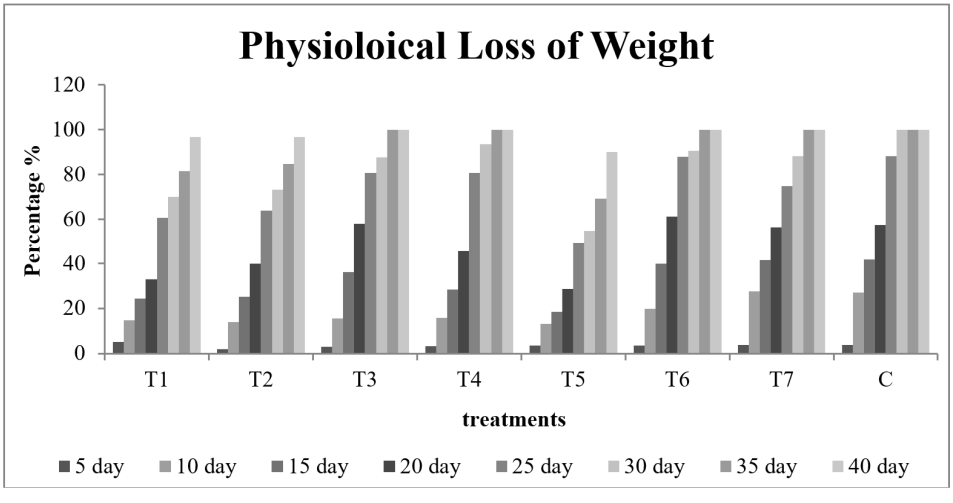
and Dunnet tests to examine if differences between treatments and storage time were significant at P < 0.05. The overall least significance difference (LSD; $p \leq 0.05$) was calculated and used to determine significant differences among all the treatments and control set (Bico et al., 2009).

3 Results and discussion

3.1 Changes in the weight loss percentage of tomato fruits

Weight loss observed in control was much more apparent than in treated fruits (Figure 1). The loss of weight might be due to the transpiration and respiration processes which affected the metabolic activity in stored tomatoes (Kumar et al., 2018). Control fruits showed about 64.76% of weight loss, while fruits treated with the combination of photosensitisation and ozone (T5) showed 40.88% weight loss till 40th d of storage. Followed by this, the tomatoes treated with photosensitisation showed 48.25% of weight loss. Reduced percentage of weight loss in tomatoes treated with ozone has also been reported by Rodoni et al (2010). The combination of photosensitisation and ozone affected the metabolic rate of stored tomatoes which resulted in the reduced loss of weight, also photosensitisation alone treatment could successfully reduce the weight loss.

Figure 1 Effect of photosensitisation, UV-C irradiation and ozone gas on physiological loss of weight (see online version for colours)



Notes: T1 – Photosensitisation alone; T2 – UV-C alone 210–280 nm; T3 – ozone gas alone (200 mg/h); T4 – photosensitisation and UV-C; T5 – photosensitisation and ozone gas; T6 – UV-C and ozone gas; T7 – photosensitisation + UV-C + Ozone gas and C – control. Different letters over the bars represents significant difference between different treatments on the same storages day at $P \leq 0.05$ according to DMRT.

Table 1 Effect of photosensitisation, UV-C irradiation and ozone gas on pH and total soluble solids

Treatments	*0 d*	*5 d*	*10 d*	*15 d*	*20 d*	*25 d*	*30 d*	*35 d*	*40 d*
					pH				
T1	4.48 ± 0.01^{f}	6.22 ± 0.28^{a}	6.75 ± 0.03^{a}	6.92 ± 0.02^{e}	7.06 ± 0.05^{ab}	7.00 ± 0.00^{bc}	7.46 ± 0.05^{b}	7.33 ± 0.1^{a}	----
T2	4.48 ± 0.01^{f}	5.66 ± 0.03^{b}	6.86 ± 0.05^{a}	7.01 ± 0.02^{b}	7.10 ± 0.05^{b}	7.23 ± 0.3^{bc}	7.66 ± 0.05^{a}	7.33 ± 0.1^{a}	----
T3	4.48 ± 0.01^{f}	5.02 ± 0.02^{c}	5.67 ± 0.48^{bc}	6.8 ± 0.08^{d}	7.07 ± 0.02^{ab}	7.34 ± 0.2^{b}	----	----	----
T4	4.48 ± 0.01^{f}	5.08 ± 0.06^{c}	6.05 ± 0.06^{b}	7.01 ± 0.17^{b}	6.99 ± 0.00^{b}	7.80 ± 0.1^{a}	7.60 ± 0.1^{a}	----	----
T5	4.48 ± 0.01^{f}	4.77 ± 0.18^{d}	5.19 ± 0.08^{c}	5.95 ± 0.08^{f}	6.16 ± 0.04^{d}	7.30 ± 0.1^{bc}	7.36 ± 0.05^{c}	7.40 ± 0.0^{a}	7.53 ± 0.05^{a}
T6	4.48 ± 0.01^{f}	4.65 ± 0.04^{de}	5.56 ± 0.15^{cd}	6.02 ± 0.0^{f}	6.18 ± 0.05^{d}	7.16 ± 0.05^{bc}	----	----	----
T7	4.48 ± 0.01^{f}	4.58 ± 0.06^{de}	6.07 ± 0.04^{b}	6.47 ± 0.02^{e}	6.21 ± 0.06^{d}	7.43 ± 0.20^{b}	----	----	----
C	4.48 ± 0.01^{f}	4.53 ± 0.04^{e}	6.67 ± 0.34^{a}	7.20 ± 0.02^{a}	6.87 ± 0.02^{c}	----	----	----	----
					TSS (%)				
T1	0.6 ± 0.05^{f}	1.2 ± 0.15^{a}	1.4 ± 0.1^{a}	1.8 ± 0.05^{b}	2.4 ± 0.17^{b}	2.5 ± 0.05^{b}	2.6 ± 0.10^{ab}	1.8 ± 0.05^{b}	----
T2	0.6 ± 0.05^{f}	1.0 ± 0.15^{ab}	1.0 ± 0.10^{bc}	1.5 ± 0.05^{cd}	2.1 ± 0.10^{cd}	2.8 ± 0.10^{a}	2.7 ± 0.05^{a}	1.9 ± 0.05^{a}	----
T3	0.6 ± 0.05^{f}	0.9 ± 0.10^{bc}	0.9 ± 0.05^{bc}	1.5 ± 0.1^{cd}	2.0 ± 0.05^{cd}	2.6 ± 0.11^{ab}	----	----	----
T4	0.6 ± 0.05^{f}	0.7 ± 0.05^{cd}	0.9 ± 0.10^{bc}	1.4 ± 0.05^{d}	1.9 ± 0.05^{d}	2.1 ± 0.15^{c}	2.3 ± 0.15^{c}	----	----
T5	0.6 ± 0.05^{f}	0.6 ± 0.15^{d}	0.8 ± 0.15^{c}	1.2 ± 0.05^{e}	1.6 ± 0.11^{e}	2.2 ± 0.20^{c}	2.4 ± 0.15^{bc}	1.9 ± 0.05^{a}	2.0 ± 0.05^{a}
T6	0.6 ± 0.05^{f}	1.0 ± 0.15^{ab}	1.2 ± 0.20^{ab}	1.6 ± 0.05^{c}	2.2 ± 0.10^{c}	2.6 ± 0.15^{ab}	----	----	----
T7	0.6 ± 0.05^{f}	0.8 ± 0.05^{bc}	1.0 ± 0.15^{bc}	1.9 ± 0.05^{b}	2.6 ± 0.10^{a}	2.6 ± 0.20^{ab}	----	----	----
C	0.6 ± 0.05^{f}	0.8 ± 0.10^{cd}	1.1 ± 0.28^{ab}	2.1 ± 0.05^{a}	2.5 ± 0.10^{ab}	----	----	----	----

Notes: T1 – Photosensitisation alone; T2 – UV-C alone 210–280 nm; T3 – ozone gas alone (200 mg/h); T4 – photosensitisation and UV-C; T5 – photosensitisation and ozone gas; T6 – UV-C and ozone gas; T7 – photosensitisation + UV-C + Ozone gas and C – Control. Different letters over the bars represents significant difference between different treatment on the same storages day at $P \leq 0.05$ according to DMRT.

Table 2 Effect of photosensitisation, UV-C irradiation and ozone gas on total phenols and antioxidant activity of stored tomato

Treatments	*0 d*	*5 d*	*10 d*	*15 d*	*20 d*	*25 d*	*30 d*	*35 d*	*40 d*
				Total phenols (g kg^{-1})					
T1	8.01 ± 0.35^{a}	13.78 ± 0.40^{a}	10.08 ± 0.45^{d}	8.61 ± 0.32^{d}	7.11 ± 0.35^{bc}	4.58 ± 0.10^{b}	3.58 ± 0.30^{b}	2.35 ± 0.05^{b}	----
T2	8.01 ± 0.35^{a}	4.51 ± 0.68^{d}	7.91 ± 0.50^{e}	7.31 ± 0.41^{e}	6.81 ± 0.47^{cd}	4.55 ± 0.20^{b}	2.38 ± 0.10^{e}	1.88 ± 0.52^{c}	----
T3	8.01 ± 0.35^{a}	7.45 ± 0.15^{c}	8.08 ± 0.45^{e}	7.55 ± 0.37^{e}	6.01 ± 0.45^{de}	2.85 ± 0.30^{d}	----	----	----
T4	8.01 ± 0.35^{a}	11.48 ± 0.45^{b}	12.91 ± 0.80^{b}	12.55 ± 0.37^{b}	7.91 ± 0.32^{b}	3.85 ± 0.35^{c}	2.25 ± 0.25^{c}	----	----
T5	8.01 ± 0.35^{a}	13.78 ± 0.40^{a}	18.85 ± 0.47^{a}	19.78 ± 0.62^{a}	19.85 ± 0.64^{a}	6.98 ± 0.43^{a}	5.25 ± 0.70^{a}	2.71 ± 0.25^{a}	2.65 ± 0.15^{a}
T6	8.01 ± 0.35^{a}	9.21 ± 0.23^{d}	6.68 ± 0.70^{f}	5.85 ± 0.32^{f}	5.38 ± 0.52^{e}	2.55 ± 0.20^{d}	----	----	----
T7	8.01 ± 0.35^{a}	9.21 ± 0.23^{c}	11.71 ± 0.58^{c}	10.85 ± 1.18^{c}	7.05 ± 0.66^{bc}	2.91 ± 0.40^{d}	----	----	----
C	8.01 ± 0.35^{a}	9.21 ± 0.23^{e}	2.58 ± 0.20^{g}	2.38 ± 0.20^{g}	1.95 ± 0.45^{f}	----	----	----	----
				Antioxidant activity (%)					
T1	42 ± 0.59^{g}	49 ± 0.37^{e}	52 ± 0.47^{e}	51 ± 0.20^{e}	51 ± 0.33^{e}	24 ± 0.13^{e}	19 ± 0.44^{e}	6 ± 2.11^{b}	----
T2	42 ± 0.59^{g}	47 ± 0.20^{d}	49 ± 0.98^{de}	49 ± 0.16^{de}	49 ± 0.32^{d}	36 ± 0.32^{d}	12 ± 0.99^{d}	6 ± 1.46^{b}	----
T3	42 ± 0.59^{g}	38 ± 0.48^{e}	42 ± 1.06^{ef}	41 ± 0.41^{f}	42 ± 0.16^{f}	35 ± 0.64^{d}	----	----	----
T4	42 ± 0.59^{g}	71 ± 0.26^{b}	74 ± 0.16^{b}	77 ± 0.16^{b}	75 ± 0.13^{b}	55 ± 0.25^{b}	38 ± 0.81^{b}	----	----
T5	42 ± 0.59^{g}	82 ± 0.55^{a}	87 ± 0.25^{a}	92 ± 0.36^{a}	93 ± 0.39^{a}	60 ± 0.54^{a}	46 ± 0.60^{a}	38 ± 3.95^{a}	38 ± 2.68^{a}
T6	42 ± 0.59^{g}	37 ± 0.33^{e}	42 ± 0.22^{ef}	42 ± 0.44^{f}	41 ± 0.52^{f}	21 ± 0.77^{e}	----	----	----
T7	42 ± 0.59^{g}	47 ± 0.28^{d}	51 ± 0.43^{cd}	51 ± 0.24^{d}	45 ± 0.06^{e}	34 ± 0.23^{b}	----	----	----
C	42 ± 0.59^{g}	35 ± 1.88^{f}	38 ± 0.57^{g}	39 ± 0.27^{g}	36 ± 0.19^{g}	----	----	----	----

Notes: T1 – Photosensitisation alone; T2 – UV-C alone 210–280 nm; T3 – ozone gas alone (200 mg/h); T4 – photosensitisation and UV-C; T5 – photosensitisation and ozone gas, T6 – UV-C and ozone gas; T7 – photosensitisation + UV-C + Ozone gas and C – Control.
Different letters over the bars represents significant difference between different treatment on the same storages day at $P \leq 0.05$ according to DMRT.

3.2 Changes in the pH and TSS of tomato fruits

In general, the pH and TSS of the freshly harvested tomatoes is lower due to its high organic acid contents which produced through Kreb's Cycle. As the storage time increased, the pH and TSS were also gradually increased. A similar increasing pattern was reported by Kumar et al. (2018). In control set, the pH and TSS observed on 0 d was 4.48 and 0.6% respectively (Table 1). On 20th d, the pH and TSS observed in control was 6.80 and 2.5% respectively. On other hand, tomatoes kept in T5 showed 6.12 and 1.6% respectively which was significantly lower than that of the control. T5 showed slower rate of increment in pH and TSS throughout the storage period; this is probably due to the combination of photosensitisation and ozone slowed down the conversion of organic acids into sugars. The similar results of slowing down of ripening of fruits were reported by Luksiene and Paskeviciute (2011) and Zambre et al. (2010).

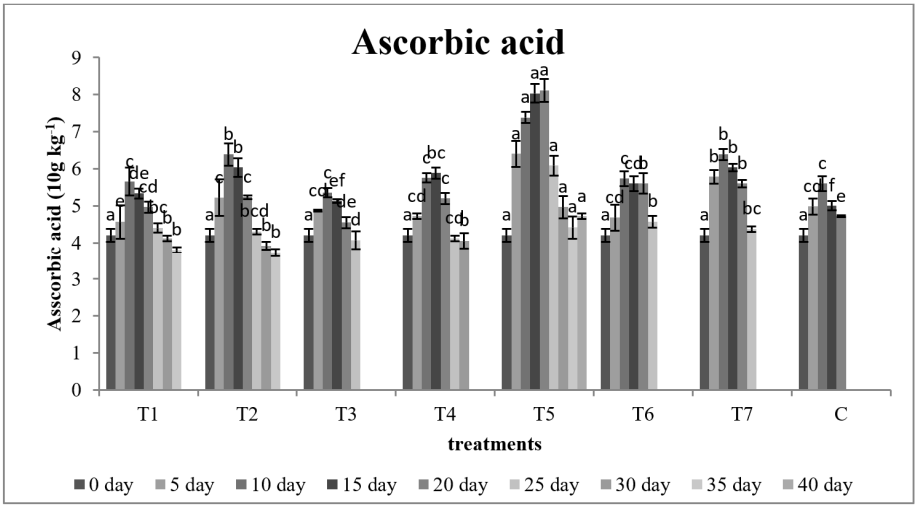
3.3 Changes in the total phenolic content and total antioxidant activity of tomato fruits

The changes in total phenolic content and antioxidant activity of tomatoes are depicted in Table 2. In general, the astringency is depending upon the phenolic contents of the fruit which gives the protection to the fruit from stress produced by either pathogen or atmosphere (Tucker et al., 1993). The amount of total phenols and antioxidant activity estimated in tomatoes treated with T5 was significantly higher ($p < 0.05$) than any other treatment throughout the storage. Total phenols present in tomatoes on very first day were 8.01 g kg^{-1}, and on 10th and 15th d of storage total phenols present in tomatoes kept in T5 were 18.85 g kg^{-1} and 19.78 g kg^{-1} respectively, while in control it showed about 2.58 g kg^{-1} and 2.38 g kg^{-1} respectively and then it decreased with storage period. On other hand, a similar pattern was observed in antioxidant activity of stored tomatoes. Antioxidant activity estimated on 0 d was 42.6% and on 5th d it reached up to 82.17% in T5, followed by 71.22% in T4 and 35.12% in control. On 20th d, the significantly higher activity was observed in T5, i.e., 93% and lowest activity was observed in 36.80% in control. This pattern of increment of phenolic compounds and antioxidant activity in tomatoes treated with T5 is might be due to these physical elicitors trigger the stress response of the fruit after harvest.

3.4 Changes in ascorbic acid content of tomato fruits

The amount of ascorbic acid got changed in treated and control fruits during the storage (Figure 2). The ascorbic acid is used as a respiratory substrate for energy generation and hence it got decreased as fruits start to ripen after harvest (Tucker et al., 1993). Ascorbic acid content was also changed on 5th d in all treated and untreated fruits than 0 d. On 15th d storage, the ascorbic acid content in the control was 0.05 10g kg^{-1} and in tomatoes treated with T5 had 0.08 10g $kg^{-1}$of ascorbic acid content which was significantly higher than that of the control or any other treatment. On 20th d of storage, where ascorbic acid content in all tomatoes including treated and control found to be decreased but and the tomatoes treated with T5 showed slight increment i.e. 0.08 10g kg^{-1}. This may due to the slow ripening and controlled metabolic rate of the fruit because of the physical elicitors.

Figure 2 Effect of photosensitisation, UV-C irradiation and ozone gas on ascorbic acid content

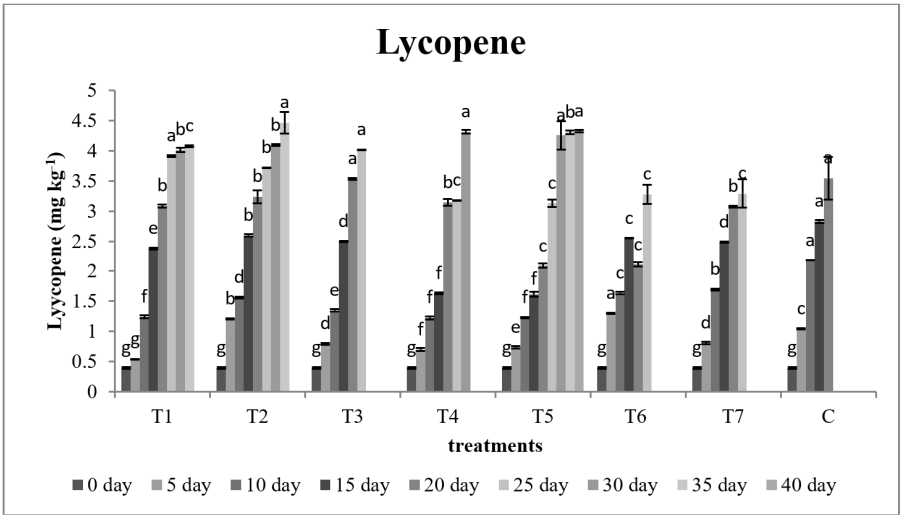


Notes: T1 – Photosensitisation alone; T2 – UV-C alone 210–280 nm; T3 – ozone gas alone (200 mg/h); T4 – photosensitisation and UV-C; T5 – photosensitisation and ozone gas; T6 – UV-C and ozone gas; T7 – photosensitisation + UV-C + ozone gas and C – control. Different letters over the bars represents significant difference between different treatments on the same storages day at $P \leq 0.05$ according to DMRT.

3.5 Changes in the lycopene and carotene content of tomato

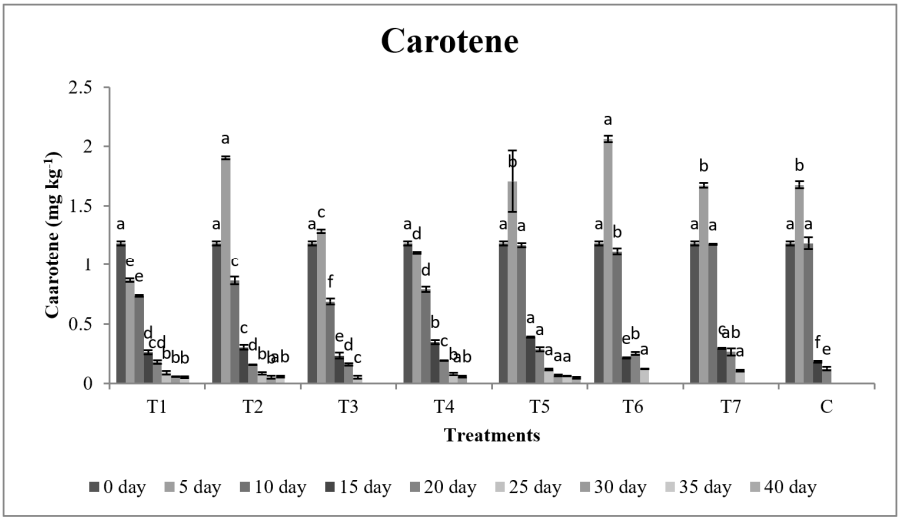
These are the most crucial components which take part in antioxidant activity of the fruit (Kumar et al., 2018). The colour changes from green to dark red were visible in all tomatoes during their growth and ripening (Figures 3 and 4). The chlorophyll degradation accompanying with the synthesis of colour pigments like carotene and lycopene takes place with the interference of enzyme chlorophyllase, which gives rise to the orange and red colour to the tomato from green colour (Paliyath et al., 2008). All the treated tomatoes showed slow rate of changing their colour from orange to red than that of the control. On 0 d, the carotene and lycopene content of tomato was 1.18 mg kg^{-1} and 0.39 mg kg^{-1}, respectively. On 5th d of storage the lycopene content in control was found highest than any other treatment, whereas on same day T5 showed significantly lower amount of lycopene content. On 20th d storage highest lycopene content, i.e., 3.54 mg $kg^{-1}$and lowest carotene content, i.e., 0.12 mg $kg^{-1}$was found in tomatoes kept in control set; while tomatoes kept in T5 showed 2.08 mg $kg^{-1}$of lycopene and 0.28 mg $kg^{-1}$of carotene content. At the end of storage, the lycopene and carotene content found in T5 was 4.32 mg kg^{-1} and 0.04 mg kg^{-1} respectively. These findings indicate that the treatment T5 could successfully slowed down the rate of conversion of carotene in to lycopene; this may due to reduced production of ethylene which directly linked to the pigment formation. The slow rate of red colour accumulation due to ozone was also noticed by Zambre et al. (2010).

Figure 3 Effect of photosensitisation, UV-C irradiation and ozone gas on lycopene content



Notes: T1 – Photosensitisation alone; T2 – UV-C alone 210–280 nm; T3 – ozone gas alone (200 mg/h); T4 – photosensitisation and UV-C; T5 – photosensitisation and ozone gas; T6 – UV-C and ozone gas; T7 – photosensitisation + UV-C + Ozone gas and C – control. Different letters over the bars represents significant difference between different treatments on the same storages day at $P \leq 0.05$ according to DMRT.

Figure 4 Effect of photosensitisation, UV-C irradiation and ozone gas on carotene content

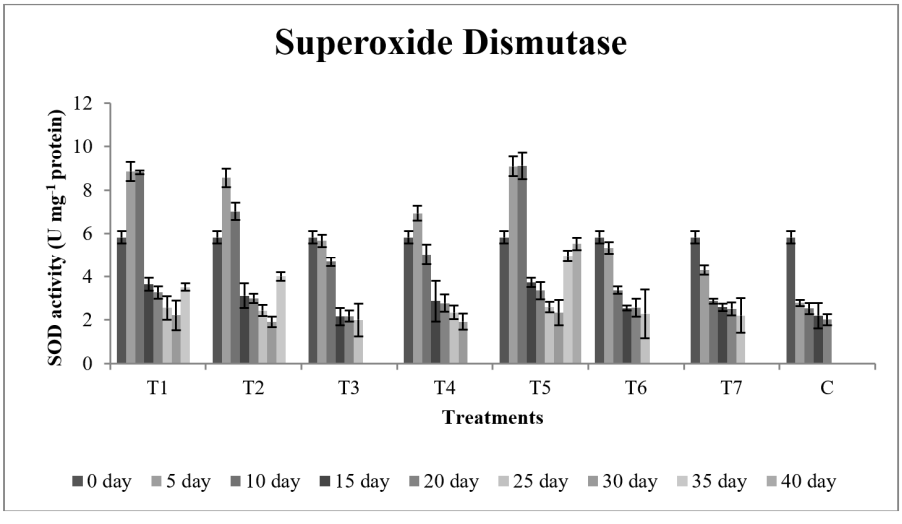


Notes: T1 – Photosensitisation alone; T2 – UV-C alone 210–280 nm; T3 – ozone gas alone (200 mg/h), T4 – photosensitisation and UV-C; T5 – photosensitisation and ozone gas; T6 – UV-C and ozone gas; T7 – photosensitisation + UV-C + Ozone gas and C – control. Different letters over the bars represents significant difference between different treatments on the same storages day at $P \leq 0.05$ according to DMRT.

3.6 Changes in the activity of antioxidant enzyme SOD of tomato

Plant inducing stress is the most important cause for increasing reactive oxygen species which damage the protective mechanism of the fruit (Ong et al., 2014). The increase in the SOD enzyme activity could hold back the production of free radicals which eventually damage the cell (Lemoine et al., 2010). Figure 5 shows the activity of SOD during the storage period. The SOD activity found in tomatoes on 0 d was 5.83 U mg^{-1} protein, while on 5th d tomatoes kept untreated showed reduced SOD activity, i.e., 2.77 U mg^{-1} protein where as T1 and T5 showed to be increased SOD activity, i.e., 8.86 U mg^{-1} protein and 9.08 U mg^{-1} protein, respectively. SOD activity of all tomatoes kept in treated as well as in control was decreased with storage time. More noteworthy results were noticed on day 10th, where control showed about 2.51 U mg^{-1} protein, the tomatoes kept in T1 and T5 showed 8.80 U mg^{-1} protein and 9.11 U mg^{-1} protein activity of SOD. It can be concluded that the T1 and T5 increased in SOD activity, which remained higher till the end of storage of the tomatoes. These results of increment of SOD activity by the physical elicitors like ozone and UV-C are in accordance with the results obtained by Gutiérrez et al. (2018).

Figure 5 Effect of photosensitisation, UV-C irradiation and ozone gas on SOD activity



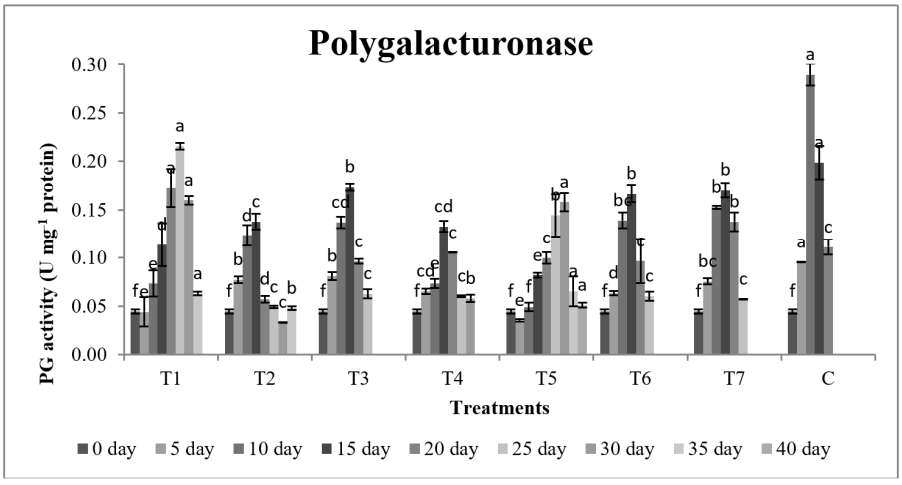
Notes: T1 – Photosensitisation alone; T2 – UV-C alone 210–280 nm; T3 – ozone gas alone (200 mg/h); T4 – photosensitisation and UV-C; T5 – photosensitisation and ozone gas; T6 – UV-C and ozone gas; T7 – photosensitisation + UV-C + Ozone gas and C – control. Error bars represents difference between different treatments on the same storages day.

3.7 Changes in the activity of cell wall degrading enzyme PG of tomato

PG plays an important task in depolymerisation of acidic pectin, and this phenomenon of this enzyme is responsible for the cell wall softening of the fruit while ripening (Gray et al., 1992). Changes in PG activity on cell wall component are depicted in Figure 6. PG enzyme activity on 0 d was 0.04 U mg^{-1} protein, while on 5th d in PG activity of control

expressed by the fruits was 0.10 U mg^{-1} protein and on other hand in tomatoes kept in T1 and T5 set expressed 0.04 U mg^{-1} protein activity of PG. More significant results were obtained on day 10th, where tomatoes treated with T5 showed 0.05 U mg^{-1} protein activities which were significantly lower than that of control, where control showed 0.29 U mg^{-1} protein activity of PG. On 15th, 20th and 25th d of storage the PG activity showed by fruits kept in T5 was found to be 0.08 U mg^{-1} protein, 0.10 U mg^{-1} protein and 0.14 U mg^{-1} protein respectively, while tomatoes kept in control set showed 0.20 U mg^{-1} protein, 0.11 U mg^{-1} protein respectively. These results indicate that the T5 and T1 able to slower down the process of production of PG. Physical elicitors slower down the mechanism of depolymerisation of pectin molecule was also reported by Toti et al. (2018).

Figure 6 Effect of photosensitisation, UV-C irradiation and ozone gas on PG activity



Notes: T1 – Photosensitisation alone; T2 – UV-C alone 210–280 nm; T3 – ozone gas alone (200 mg/h); T4 – photosensitisation and UV-C; T5 – photosensitisation and ozone gas; T6 – UV-C and ozone gas; T7 – photosensitisation + UV-C + ozone gas and C – control. Different letters over the Bars represents significant difference between different treatment on the same storages day at $P \leq 0.05$ according to DMRT.

4 Conclusions

The obtained results of the above conducted study conclude that the combination of physical elicitors like ozone gas and photosensitisation could successfully enhance the shelf life along with the maintenance of the antioxidant system of the tomatoes. This treatment of photosensitisation is novel and it did not negatively affect the fruit physiology and its nutritional composition. This combination successfully enhanced the shelf life of tomatoes by 18 d more than that of the control. Along with the enhancement of shelf life, this treatment also preserved the nutritional qualities. Further, the detailed study can also be conducted to check the efficacy of the photosensitisation treatment with or without other physical elicitors like ozone and UV-C on shelf life and postharvest diseases of any horticultural produce.

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