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Enhancing postharvest shelf life and quality of tomato (*Solanum lycopersicum* L.) by postharvest applications of Enhanced freshness formulation (EFF)

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Abstract
An experiment was conducted to study the effect of Enhanced freshness formulation (EFF) at three different concentrations @1, 2, 3 per cent, water dipping and absolute control on extension of shelf life and quality of Tomato var.PKM1. The experimental materials were stored under ambient condition (28 °C ± 2 °C, RH 60 ± 10%) and cold storage condition (13 °C ± 2 °C, RH 90 ± 5%).Observations on physical, (Firmness), Physiological loss in weight (PLW) biochemical parameters and color value of the vegetables were studied. The fruits treated with EFF at one and two per cent (T2 and T3) recorded minimum PLW with maximum fruit firmness and shelf life of the fruit was six and nine days under ambient and cold storage, low TSS and high percentage of acidity with less total colour difference from standard value stored under ambient (28 ± 2^0 c) and cold storage @13 ± 2^0 c condition.

Keywords: *Solanum lycopersicum* L, postharvest, EFF, shelf life, colour value

Introduction

Tomato (*Solanum lycopersicum* L.) is one of the most widely cultivated and extensively consumed vegetable crops globally (Grandillo *et al*., 1999) [4]. Although the crop is believed to have been originated from the wild in Peru, Ecuador, and other parts of tropical Americas (Rick and Butler, 1956) [15], the nutritional and economic importance of the crop has led to its global production. By weight, tomatoes rank second only to potatoes in global production of all horticultural produce (Tan *et al.*, 2010) [19]. Tomato can be consumed in various ways and in a countless number of dishes. It can be eaten raw in salads or as an extract or sauce in many dishes and in drinks (Alam and Goyal, 2007) [1]. Tomato and tomato-based foods provide a wide variety of nutrients and many health-related benefits to the body. Tomato being a perishable crop as a result of its high moisture content has short shelf life of about 48 hours under tropical conditions. Specialised postharvest handling practices and treatment methods are needed in order to extend the shelf life of the crop after harvest. Failure to adhere to these specialised handling practices and treatment methods will result in high amount of loss. Losses of up to 50% can be recorded in tomatoes between the harvesting and consumption stages of the distribution chain in tropical countries It is therefore important to know the appropriate handling practices and treatment methods needed for harvested tomatoes in order to reduce postharvest losses thereby increasing profitability for handlers in developing countries.

Fruits and vegetables are extremely perishable products that require to be dealt with much care to reduce losses. Even though research efforts have been made to increase the production of tomato to some extent, the purpose of obtaining maximum profit will be served only if the increased production is supplemented with similar efforts to minimize the postharvest losses and enhance the shelf life. Hexanal is an aldehyde, produced during the termination phase of fat oxidation in plant materials, known to extend shelf life of many horticultural commodities by inhibiting enzyme phospholipase D activity, which hydrolyzes the phospholipid to phosphatidic acid and a free head group. Phospholipase D enzyme gradually stimulated during the fruit ripening process in an autocatalytic manner, which results in membrane degradation and destabilization. Hexanal is highly volatile and had antifungal properties against *Alternaria alternata, Botrytis cinerea and Penicillium expansum.*

Materials and Methods
The present investigation was carried out at Dept of Floricultre and Land scape Architecture, Horticultural College and Research Institute, TNAU Periyakulam, during the 2019-2020., with the aim to extend the shelf life of Tomato var. PKM1 through postharvest application of Enhanced Freshness Formulation (EFF). The treatments included EFF at three different concentrations *ie*., 1% (T1),2% (T2),3% (T3), water dip (T4) and Absolute control (T5). Fruits were treated with EFF for 5 minutes and the treated produce were air-dried. Treated and untreated samples were stored under ambient (28°C ± 2°C, RH 60 ± 10%) and cold room (13°C ± 2°C, RH 90 ± 5%) conditions. During storage period observations were recorded on Physiological loss in weight (PLW), Firmness (kg/cm3), shelf life (days) and quality parameters *viz.,* acidity (per cent) ascorbic acid (mg/100g), TSS (^{0} Brix), and color value of the fruit (L,a, and b) was determined using standard operational protocols, Design of experiment followed in the study was completely randomized design (CRD) with four replications consisting of five treatments tested under ambient and cold storage condition.

Physiological loss in Weight (%): It was determined by periodical weighing of fruits and expressed as percentage of original weight. Damaged (rotting or chilling injury) fruits were also included with it.

$$\text{PLW (\%)} = \frac{\text{Initial weight - Final weight}}{\text{Initial weight}} \text{ X 100}$$

Fruit firmness
Fruit firmness was measured on opposite sides of the equatorial axis using fruit pressure tester model FT 27(1227 lbs) with a plunger 5/16 inches was used for the determination of rupture force and the readings were expressed as kg/cm3

Shelf life (day): The fruits were stored under ambient storage (27± 2 ºC) and cold storage (13± 2 ºC) conditions. The shelf life of fruits were determined by recording the number of days the fruits that remained in good condition in storage at both room and cold temperature. The stage where in more than 25-30 per cent moisture loss and 35 per cent spoilage was noted and expressed as number of days of shelf life (Padmalatha, 1993) [13].

Total Soluble Solids
The total soluble solids of the fruits were determined with the help of Erma hand refractometer with range 0-32 *per cent* and the values were expressed in degree brix after making the temperature correction at 20 ºC.

Titratable Acidity
The titratable acidity was estimated by titrating 10 ml of juice against 0.1 N NaOH, using 1 per cent phenolphthalein as an indicator. Acidity was expressed as per cent of citric acid. (Rangana, 1986) [16].

$$\text{Acidity (\%)} = \frac{\text{Titre x Normality of alkali x 0.0064 x 100}}{\text{Volume of the sample taken (ml)}}$$

Ascorbic acid
Ascorbic acid content of the sapota fruit flesh was estimated using 2, 6-dichlorophenol indophenols dye visual titration method and expressed in mg/100g (Rangana, 1986) [16].

Color value
The color value of the fruit skin and flesh were measured in Food Quality Testing Laboratory, CPHT, TNAU, CBE and colour difference was identified using L* a* b*coordinates and found that the sample value match with standard colour value (Hunter Lab 2012, Hunter Associates Laboratory Inc,USA,WWW.hunterlab.com).

Statistical analysis
Effect of postharvest dip of EFF on the observed parameters were analysed in a Completely Randomized Design at 5 % significance level using AGRESS software.

Results and Discussion
Effect of enhanced freshness formulation and water dip on physiological loss in weight (PLW) % and biochemical qualities and color value of Tomato var. PKM1 under ambient (28±2^{0}c) and cold storage (13±2^{0}c) were recorded.

The minimum per cent loss in weight (9.60) was observed in T2 (EFF @ 2%) and maximum loss (16.70%) was recorded in T5 (control). Among the treatments, T2 and T3 (EFF @ 2 and 3%) recorded significant minimum weight loss of 9.60 and 10.15 per cent on sixth day after storage. However T2 (EFF at 2%) was on par with T3 (EFF at 3%) under ambient storage condition. Under cold storage condition, the fruits were stored up to eight days. The fruits treated with 2 *per cent* EFF recorded minimum weight reduction of 0.35 per cent on second day after storage and the reduction was 2.83 per cent on 9th day after storage followed by T3 (EFF @ 3%), T4(water dip) T1 (EFF @ 1 %) and control were exhibited that the weight reduction was 2.96, 3.50, 3.90 and 4.70 per cent on eighth day after storage. (Table 1,1a, Fig1&1a)

The data pertaining to the fruit firmness showed significant differences among the treatments studied under ambient and cold storage condition. The mean values varied from 1.70kg/cm^3 in T5(Control) to 2.60 kg/cm^3 in T3(EFF@3%) under ambient storage condition. The treatment T3 was on par withT1 and T2 (EFF @1 and 2%) which recorded the firmness of 2.59 and 2.51 kg/cm^3. Total soluble solids (^{0} Brix) ranged from 3.75 ^{0} Brix in T4 (water dip) to 5.15 ^{0} Brix in T5 (control). Significant differences were observed among the treatments with respect to acidity. Percentage of acidity was ranged from 0.21 to 0.39. Highest acidity (0.39 %) was recorded in the treatment T2 (EFF @ 2%) followed by T1 (EFF @ 1%) 0.36 per cent. Lowest acidity (0.21%) was recorded in the treatment T4 (waterdip). No significant differences were observed among the treatments for ascorbic acid content. It ranged from 22.50 mg/100g in T4 (water dip) to 27.50 mg/100g in T1 (EFF @ 1%).

Firmness of the fruit showed significant differences among the treatments studied under cold storage condition. The mean values varied from 1.82 kg/cm^3 (Control) to 2.71 kg/cm^3 in T3 (EFF@ 3%) under cold storage condition. The treatment T3 (EFF@ 3%) was on par withT1 and T2 (EFF @ 1 and 2%) which recorded the firmness of 2.70 and 2.60kg/cm3. Total soluble solid (^{0}Brix) was ranged from 3.25^{0}Brix in T3 (EFF @ 3%) to 4.14 ^{0} Brix in T5 (control). Significant differences were observed among the treatments with respect to acidity. Percentage of acidity was ranged from 0.17 to 0.45. Highest acidity (0.45 %) was recorded in the treatment T1 (EFF at 1%) followed by T2 (EFF @ 2%) of 0.42 per cent. Lowest acidity (0.17%) was recorded in the treatment T5 (control). There were no significant differences among the treatments for ascorbic acid content. It was ranged from 23.75 mg/100g in T1(EFF @ 1%) to 28.33 mg/100g in T4 (water dip) (Table.2 &Fig.2)

Colour value of the sample from the treatments T1,T3 and T4 (EFF @1%,3% and water dip) showed less lighter (L=69.96, 69.70 and 69.53) more red (13.69,13.56 and 13.22 in) and less yellow (24.01,21.52 and 21.45) in T1,T2 and T3 than standard (L=72.02, a=11.56, b=26.55) whereas, T5 (control) recorded lighter, less red and yellow (L=66.32., a=9.76 b=19.43) than standard Total color difference Δ E was minimum in T1 (ΔE=3.90) followed by T3(ΔE=5.91),T4(ΔE =6.09), T2(ΔE=6.3) and in T5 (ΔE=9.24) under ambient condition.

Under cold storage condition, colour value of the samples from treated and control showed that lighter (L=74.30,72.27,73.31,78.50 and 73.0), more red (a= 11.52,14.93,12.77, and 12.30 except T1 which recorded less red (8.52) than standard (a=11.56) and more yellow (27.28,27.84, and 28.84) in T1,T4 and T5 whereas T2 and T3 recorded less yellow (25.99 and 25.06) than standard (L=72.02,a=11.56 and b= 26.55)). Total colour difference Δ E was minimum in T2 (ΔE=0.61) followed by T5 (ΔE =2.64), T1(ΔE=3.86) and in T3 (ΔE=3.90) (Table 1d). (Table 3,3a Fig 3 &3a).

Over all, the data have clearly indicated that dipping of tomato fruits in hexanol formulation can extend the shelf life with a result of series of physiological, biochemical and morphological changes. Treated fruits exhibited reduction in PLW and increased firmness while maintaining the quality attributes such as sugar and ascorbic acid the technology described here provides a safe and efficient strategy for enhancing shelf-life and nutritional quality of tomatoes.

Discussion

The physiological loss in weight might be due to the water loss, respiration and transpiration of tomato even after the harvest. Fresh produce continues to lose water transpiration and respiration even after harvest due to resulting in wilting or shrivelling of the produce which otherwise called as physiological loss in weight. Above five per cent moisture loss is enough to make the produce shrivel and making it unattractive for marketing. Relative humidity and temperature are the important factors that influence the loss of moisture from fresh produce Water loss will also be high with increase in storage temperature. Fresh produce transpire more at high temperatures and low humidity. (Tsomu and Patel, 2014) [21].

In the present study, EFF treatment reduced the microbial load and moisture loss thus extended shelf life by reducing the weight and moisture loss. The same finding was reported by Nasrin *et al.* (2008) [12] in tomato fruits when they were dipped in 200ppm chlorine solution for 5 minutes. The lowest hexanol treated fruits may be attributed to the thickening of cell wall as a consequence of lipoygenase inhibition. Biochemical changes induced after the application of the hexanol formulation may have helped preserve the membrane integrity and cell structure resulting in reduced catabolic process and quality losses (Paliyath and Subramanian, 2008; Tiwari and Paliyath, 2011) [14, 20]. Enhanced Freshness Formulation recorded higher firmness under ambient and cold storage. This is due to action of hexanol that reduces the activities of enzymes promoting pectin and hemicellulose degradation. This is due to the action of hexanal that reduces the activities of enzymes promoting pectin and hemicellulose degradation. Softening of fruit is caused either by breakdown of insoluble protopectin into soluble pectin in most fruit or by hydrolysis of starch as in banana (Lohani *et al*., 2004) [8]. The loss of pectic substances in the middle lamella of the cell wall is a key step in the fruit ripening process that leads to the loss of cell wall integrity resulting in fruit ripening. EFF treated tomatoes, transcript levels of polygalacturonase involved in pectin degradation were down regulated resulting in enhanced firmness and keeping quality (Tiwari and Paliyath, 2011a) [20]. Similar finding of increase in firmness when treated with hexanal was also reported by Gill *et al.* (2016) [5] and Nandhini (2017) [11] in Guava fruits. Yuan *et al.* (2008) [22] reported that the strawberry fruit treated with hexanal formulation (EFF) by post-harvest dipping resulted a lower TSS (Brix) content during storage, probably due to reduction in the respiration rate and delayed ripening which is in accordance with the present experiment results. The lower soluble solids under cold room condition may be due to the inhibition of acid metabolism and dehydration and thus reduces soluble sugar concentration.

The decrease in acid content of fruit during storage could be attributed to the use of organic acids in respiratory process by the fruit at a higher level than the fruit subjected to EFF sprays or calcium nitrate sprays (Killadi *et al.* 2007) [7]. Fruit treated with EFF and calcium maintained a higher acidity value during storage, possibly due to a reduction in the respiration rate, and delayed ripening. Similar results have been reported by Mondal *et al.* (2009) [10] in guava fruit, Sharma *et al.* (2010) [17] in cherries and Gupta *et al.* (2011) [6] in guava. The decrease in ascorbic acid during storage is due to conversion of ascorbic acid to dehydroascorbic acid by the action of ascorbic acid oxidase (Singh *et al*., 2005) [18]. Cheema *et al.* (2014) [3] also observed an increase in ascorbic acid content in greenhouse tomato, due to pre-harvest hexanal application. The present investigation results revealed that the decreasing trend on ascorbic acid content during the storage period in control fruits (untreated with EFF) than treated fruits which showed higher ascorbic acid content owing to hexanal that reduces the rate of respiration and conversion of ascorbic acid to dehydroascorbic acid. The gradual decline in ascorbic acid in EFF treated fruits might be due to increased biosynthesis or decreased oxidation during storage. Similar finding was also reported by Ajith (2016) [1] in mango var. Neelum and Alphonso, which showed higher ascorbic acid content in response to post-harvest application of hexanal formulation (EFF) than the control and Nandhini (2017) [11] in Guava. Changes in colour intensity and quality are important indicators of maturity and quality for fresh tomatoes and development of red colour is considered as an index of maturity (Lopez Camelo and Gomez, 2004) [9] Effectiveness of EFF on slowing down senescence was also reflected in postharvest dip applications. Tomatoes dipped in EFF showed higher L values, hue angle, and reduced red colour intensity than control fruit during storage, suggesting a delay in ripening. These results are in agreement with our earlier observations (Tiwari and Paliyath, 2011a) [20].

Table 1: Effect of enhanced freshness formulation and water dip on physiological loss in weight (PLW) per cent in Tomato var.PKM1 five days after storage under ambient condition (28 ± 2^0c)

Treatments	Day2	Day3	Day4	Day5	Day6
T1	1.65	2.55	3.90	6.50	12.00
T2	1.02 *	2.10*	3.35*	5.90*	9.60*
T3	1.13*	2.32*	3.60*	6.30*	10.15*
T4	1.70	2.98	4.30	6.95	13.40
T5	1.69	3.10	4.50	7.30	16.70*
SEd	0.09	0.18	0.12	0.21	0.23
CD (0.05)	0.23*	0.42*	0.32*	0.45*	0.60*

Table 1a: Effect of enhanced freshness formulation and water dip on physiological loss in weight (PLW) per cent in Tomato var. PKM1 eight days after cold storage (13±2 ^{0}c)

Treatments	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9
T1	0.65	0.90	1.20	1.49	1.65	2.60	3.10	3.90
T2	0.35*	0.69*	0.91*	1.10*	1.38*	1.70*	2.40*	2.80*
T3	0.49	0.80	0.99	1.25	1.40	1.90	2.50	2.96
T4	0.63	0.93	1.10	1.30	1.76	2.10	2.90	3.50
T5	0.82	1.14	1.34*	1.60*	1.89	2.80*	3.50*	4.70*
SEd	0.10	0.07	0.08	0.16	0.10	0.19	0.20	0.26
CD (0.05)	0.29*	0.24*	0.18*	0.30*	0.18*	0.35*	0.43*	0.60*

Table 2: Effect of enhanced freshness formulation and water dip on fruit firmness (kg/cm3), TSS (^{0}Brix), Acidity (%) and Ascorbic acid (mg/100g) content of Tomato var. PKM1 stored under ambient and cold storage condition

Treatments	Ambient storage (Five days after storage 28±2 ^{0}c)				Cold storage (eight days after storage 13±2 ^{0}c)			
	TSS (^{0} B)	Acidity (%)	Ascorbic acid (mg/100g)	Firmness (kg/cm^2)	TSS (^{0} B)	Acidity (%)	Ascorbic acid mg/100g)	Firmness (kg/cm^2)
T1	4.44	0.36	27.50	2.59	4.01	0.45	23.75	2.70
T2	4.03	0.39	23.75	2.51	4.05	0.42	25.00	2.60
T3	3.75	0.22	20.83	2.60	3.25	0.19	26.67	2.71
T4	3.75	0.21	22.50	1.70	3.75	0.17	28.33	1.82
T5	5.15	0.27	23.00	2.48	4.24	0.37	27.50	2.64
SEd	0.282	0.027	3.364	0.191	0.286	0.027	4.428	0.099
CD(0.05)	0.600**	0.058**	7.170 ^{NS}	0.407**	0.610*	0.058	9.439^{NS}	0.210**

Table 3: Effect of enhanced freshness formulation and water dip on colour value of Tomato variety PKM1 under ambient storage (28±2 ^{0}c)

Treatments	L*	ΔL	a*	Δa	b*	Δb	ΔE
T1	69.95	-2.07	13.69	2.13	24.01	2.54	3.90
T2	68.00	-4.02	13.56	2.04	21.52	4.47	6.33
T3	69.70	-2.50	13.22	1.66	21.45	-5.1	5.91
T4	69.53	-2.49	11.58	0.02	20.99	-5.56	6.09
T5 (Control)	66.32	-5.70	9.76	-5.56	19.43	-7.12	9.24
Fresh vegetables(standard)	72.02		11.55		26.55		

Table 3a: Effect of enhanced freshness formulation and water dip on colour value of Tomato variety PKM1 under cold storage (13±2^{0}c)

Treatments	L*	ΔL	a*	Δa	b*	Δb	ΔE
T1	74.30	2.28	8.52	-3.04	27.28	0.73	3.86
T2	72.37	0.25	11.52	-0.04	25.99	-0.56	0.61
T3	73.31	1.29	14.93	3.37	25.06	-1.49	3.90
T4	78.50	6.48	12.77	1.21	27.84	1.29	6.71
T5 (Control)	73.05	1.03	12.39	0.83	28.84	2.29	2.64
Fresh vegetables(standard)	72.02		11.56		26.55		

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