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Comparison of Ethylene Sensitivity of Three Tomato Cultivars From Different Tomato Types and Effects of Ethylene on Postharvest Performance

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ABSTRACT

The aim of study was to investigate ethylene sensitivity of different types of tomatoes and the effects of ethylene on their postharvest performance. For that purpose, beefsteak, heirloom and cluster types of tomato fruit were harvested at the breaker maturity stage and divided into two groups one of which was treated with 150 µL L^{-1} ethylene and the other was untreated for comparison. Ethylene treated and untreated fruit were stored at 12 °C and 90±5% relative humidity for 35 days and subsamples removed every 7 days for postharvest quality analysis. After each removal time, fruit were kept at 20 °C for 3 days in order to determine shelf life performance. Ethylene treatment lead to increase respiration rate, ethylene production, weight loss but decreased fruit firmness in all tested tomato cultivars. Minimum ethylene production and respiration rate occurred in untreated beefsteak tomatoes. At the end of cold storage and shelf life period, the highest *L** values and fruit firmness were recorded for control beefsteak tomatoes. The conclusion drawn from this experiment was that the cluster type of tomatoes was more sensitive, while beefsteak type of tomatoes was found to be less sensitive to ethylene treatment as they had the highest and lowest amount of ethylene productions respectively. Untreated beefsteak tomatoes exhibited maximal postharvest quality compared to other treatments after 35 days cold storage and shelf life.

Keywords: Cold storage, Ethylene, Quality, Respiration rate, Shelf life, Tomatoes

1. Introduction

Internationally tomato is the leading vegetable with an annual production of 177 million tons (MT). China ranked 1st with the production of 61.6 MT whereas Turkey ranked 4th with 12.1 MT production (FAO 2018). Approximately 70% of tomatoes are freshly consumed while the remaining 30% of tomatoes are processed for making tomato sauce and a range of tomato-based products including ketchup and juice (Erturk & Cirka 2015). Tomato, being a climacteric fruit, is highly sensitive to the ripening hormone ethylene. Ethylene induces the ripening of climacteric fruit and is highly effective in modulating biochemical reactions in fruit. Ethylene affects not only biochemical composition but also increases respiration rate and senescence of fruit and vegetables (Prasanna et al. 2007). Additionally, chlorophyll degradation and softening of tomato fruit are caused by ethylene (Akbudak et al. 2007). Effects of ethylene in horticultural produces are mainly dependent upon the cultivar, maturity stage, application dose and temperature (Nagata et al. 1995; Wills et al. 1998; De Wild et al. 2005). Endogenous or exogenous treatment of ethylene is widely used to stimulate and initiate ripening in climacteric fruits. Ethylene is applied to fruit for ripening and improvement in quality of color (Dhall & Singh 2013). Similar to other fruits and vegetables, maturation causes changes in color, texture, flavor and chemical structure of tomatoes.

The attainment of consumer satisfaction is a challenging task for marketing and therefore breeders are introducing different tomato types and cultivars every year. Respiration rate, ethylene sensitivity, sugars, acids and other biochemical properties vary according to type of tomatoes. In general, tomatoes with higher sugar and acid content have a better taste than those with lower acid and sugar content (Cantwell 2010).

Ethylene production by tomato fruit varies according to type and maturity stage of fruit (Baldwin 2004). Different tomato types show different ripening behavior. Therefore, it is important to determine the response of ethylene in these different types of tomato to benefit commercial growers, breeders, wholesalers and retailers. Therefore, the aim of study was to investigate ethylene sensitivity of different types of tomatoes and the effects of ethylene on their postharvest performance.

2. Material and Methods

Beefsteak (cv. Tybif), heirloom (cv. Yuksel Koy) and cluster (cv. Merkur) types of tomato were harvested at 'breaker stage'. All fruits were obtained from a commercial greenhouse in Antalya, Turkey (36°59'57.3" N 30°51'20.4" E). During the entire vegetation period, uniform irrigation and fertigation management procedures were applied to the tested tomato types. All fruits were harvested on the same day and fruit were immediately transported to the postharvest physiology laboratory at Akdeniz University, Antalya, Turkey. Fruit with any defects i.e. decayed, bruised and non-uniform, were discarded and the remainder were split into two groups. The first group was treated with 150 µl L^{-1} of ethylene at 20 °C in a 20 m^3 room for 40 min and the second group was left untreated (control). Both groups of fruit samples were stored at 12 °C and 90±5% relative humidity for 35 days. Fruit samples for quality analysis were removed from storage at 7 days intervals and kept at 20 ºC and 60±5% relative humidity for additional 3 days to simulate shelf life performance.

For ethylene production, 10 fruits from each treatment were enclosed in 5 L airtight jars for 1 h at 20 °C, then a 1 mL gas sample was withdrawn using a gastight syringe and injected into a gas chromatography (GC; Finnigan Trace Ultra, Thermo Electron S.p.A. Strada Rivoltana 20900 Radano, Milan-Italy) equipped with GS-GASPRO, 113-4362 Capillary column, 60 m x 0.322 mm calibrated with standard ethylene. The temperature of detector, oven and injection were 170 °C, 90 °C and 100 °C, respectively. Flow rates of carrier gas helium, air and hydrogen were 25 mL min^{-1}, 350 mL min^{-1} and 35 mL min^{-1}, respectively. Ethylene production was reported as µL C_2H_4 kg^{-1} h^{-1} (Dogan et al. 2017).

Respiration rates of fruits were measured as CO_2 production. For that purpose, 10 fruits from each treatment were enclosed in 5 L airtight jars for 1 h at 20 °C, then a 1 mL gas sample was taken from the headspace and injected into GC equipped with 80/100 Porapak N, 182.88 cm x 0.635 cm column calibrated with standard CO_2. The temperatures of detector, oven and injection temperature were 100 °C, 65 °C and 100 °C, respectively. Flow rates of carrier gas helium, air and hydrogen were 10 mL min^{-1}, 400 mL min^{-1} and 45 mL min^{-1}, respectively. Respiration rates were reported as mL CO_2 kg^{-1} h^{-1} (Dogan et al. 2017). The ethylene production and respiration rate analysis were carried out with the same tomatoes for 35 days of storage.

Weight loss was determined by weighing tomatoes at the beginning of the experiment (day 0) and at 7 days intervals. Cumulative weight loss was expressed as percentage loss of the initial total weight.

Color changes of tomatoes were recorded with a color meter (CR-400, Minolta, Ramsey, NJ, USA), which directly gave CIE L^*, hue angle ($h°$) and chroma (C^*) values. Color measurements were made from 3 different points on the equatorial region of the fruit surface to represent the entire fruit sample. (Mcguire 1992). Total soluble solids (TSS) content was measured with a digital refractometer (Hanna HI 96801) and the TSS was expressed as percent (%). For titratable acidity (TA), the juice of tomato fruit was obtained using a blender. Determination of TA was done by titrating a juice sample of 2 mL with 38 mL of distilled water along with 0.1 N NaOH to an end point of 8.1. Each sample was titrated three times and means calculated. The TA was determined as g citric acid kg^{-1}. Fruit firmness of tomato was measured using a penetrometer (FT 011) with 3 mm plunger. Measurements were carried out on three different points of each fruit and firmness was determined in Newton (N). The amount of unmarketable fruit was expressed in percent. The calculation was done according to the following equation (1) used by Jan & Rab (2012).

Amount of unmarketable fruit (%) = number of deteriorated fruit/ total number of fruit x100 (1)

A completely randomized design with three replications was used for the experiment. Each replication contained ten fruits. Means calculated were subjected to Duncan's multiple range test to determine significant differences. Mean values obtained were analyzed with SAS program.

3. Results and Discussion

3.1. Ethylene production and respiration rate

3.1.1. Ethylene production

Ethylene treated heirloom and beefsteak types of tomato had maximum ethylene production after 21 days storage compared with 28 days for the same types without ethylene treatment. Both control and ethylene treated cluster type tomatoes reached peak ethylene production after 21 days. Maximum ethylene production (3.527 µL C_2H_4 kg^{-1} h^{-1}) occurred in the ethylene treated cluster type with the least ethylene (1.225 µL C_2H_4 kg^{-1} h^{-1}) in control beefsteak tomatoes (Figure 1).

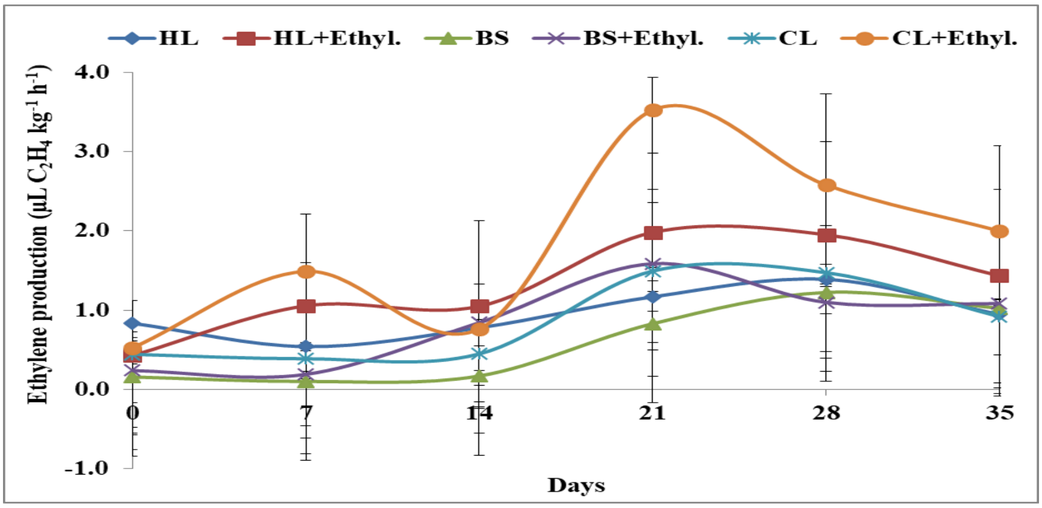

Figure 1- Effect of 150 µl L^{-1} ethylene treatment on ethylene production in different types of tomatoes at 12 °C. Vertical lines represent standard deviations of the means (n=3). †BS = Beefsteak, BS+Ethyl. = Beefsteak+Ethylene, HL= Heirloom, HL+Ethyl. = Heirloom+Ethylene, CL= Cluster, CL+Ethyl.= Cluster+Ethylene

Extension in storage resulted in increase of ethylene in this study with higher ethylene production in ethylene treated fruit which agreed with the result of Chomchalow et al. (2002) who reported an increase in ethylene production with advanced ripening in tomatoes treated by ethylene. Maximum ethylene production was obtained in ethylene treated fruit during our study as compared to untreated fruit which agreed to the outcome of Dong et al. (2001) who reported that ethylene treated 'Flavortop' nectarines had higher ethylene production.

3.1.2. Respiration rate

Control heirloom type had a climacteric maximum after 35 days of storage compared with 14 days for ethylene treated heirloom tomatoes. Control beefsteak type reached a climacteric maximum in 14 days while ethylene treated beefsteak type of tomatoes had climacteric maximum on 28th day of storage. Control cluster type of tomatoes reached climacteric maximum on 35th day with ethylene treated cluster type had climacteric maximum on day 0. Maximum respiration rate of 2.171 mL CO_2 kg^{-1} h^{-1} occurred in control cluster type after 35 days storage with minimum respiration rate of 1.072 mL CO_2 kg^{-1} h^{-1} occurred in control beefsteak type of tomatoes 14 days after storage (Figure 2).

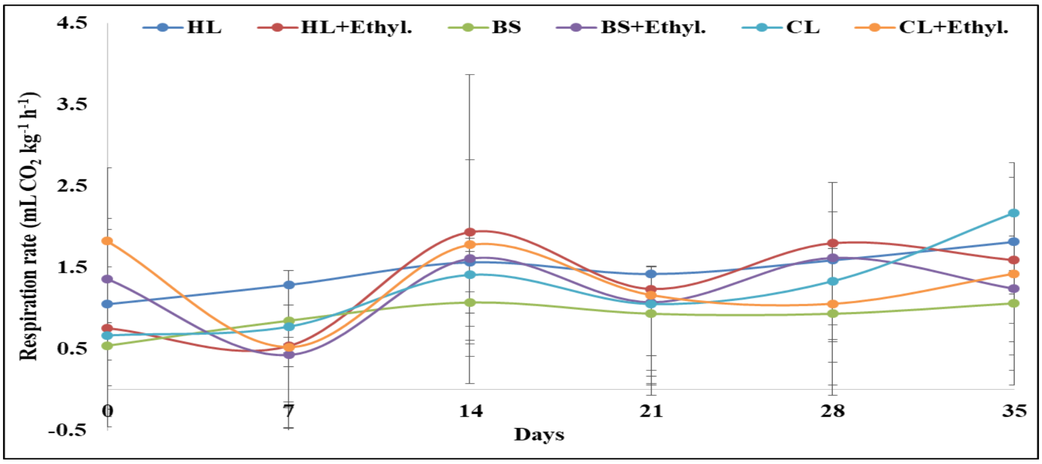

Figure 2- Effect of 150 µl L^{-1} ethylene treatment on respiration rate in different types of tomatoes at 12 °C. Vertical lines represent standard deviations of the means (n=3). †BS = Beefsteak, BS+Ethyl.= Beefsteak+Ethylene, HL = Heirloom, HL+Ethyl.= Heirloom+Ethylene, CL= Cluster, CL+Ethyl. = Cluster+Ethylene

Rise in respiration rate of tomatoes was observed by Karacali (1990) as noticed in our study. Boe & Salunkhe (1967) in tomatoes and Elmi et al. (2017) in strawberries reported that the ethylene treatment increased the rate of CO_2 production. However, their outcome contradicted with cluster type tomatoes where control treatment had higher CO_2 production than ethylene treated tomatoes. Respiration rate of tomato fruit is one of the vital indicators of senescence climacteric fruit (Maharaj et al. 1999). Similarly, according to Gonzalez-Aguilar et al. (2010) respiration rate and ethylene productions are main components to determine decay incidence of fruit and vegetables.

3.2. Weight loss

Ethylene treatment in all tomato types resulted in higher amount of weight loss in the fruit. Weight loss of tomatoes increased both in cold storage and shelf life during storage period. After cold storage, greatest weight loss (5.90%) was from ethylene treated cluster fruit whereas lowest weight loss (2.37%) was in control beefsteak tomatoes (Table 1). At the end of 35+3 days storage and shelf life period, maximum weight loss (8.48%) occurred in ethylene treated cluster tomatoes whereas minimum weight loss (3.84%) occurred in control beefsteak tomatoes (Table 2). The interactions between storage duration and treatments were significant in both cold storage and shelf life conditions at P≤0.05.

Table 1- Effect of ethylene on weight loss, color (*L, *C**, *h*°), total soluble solids, titratable acidity, fruit firmness and amount of unmarketable fruit of different types of tomatoes during storage at 12 °C**

Parameters	*Treatments*	*Storage duration (Days)*					
		0	**7**	**14**	**21**	**28**	**35**
Weight loss (%)	**BS**[†]	-	0.68jk*	0.87jk	1.09jk	1.60fk	2.37df
	BS+Ethyl.	-	0.53k	0.89jk	1.16hk	2.21dh	3.25bd
	HL	-	0.49k	0.80jk	1.00jk	1.60fk	2.40df
	HL+Ethyl.	-	0.65jk	0.94jk	1.20gk	2.10ei	2.85ce
	CL	-	0.64jk	1.72fj	2.08ei	3.68bc	5.11a
	CL+Ethyl.	-	0.63jk	1.20gk	2.27dg	4.13b	5.90a
	$LSD_{5\%}$: St. Dur.: 0.4131 **St. Dur. × Trt.:** 0.9237 **Trt.:** 0.3771						
Brightness (*L)**	**BS**	54.69a	54.36ab	54.03ab	52.85ae	53.33ad	50.18ah
	BS+Ethyl.	53.67ad	53.84ac	53.37ad	49.89bi	48.46ei	46.23hl
	HL	52.30af	50.94ag	49.13di	46.61gk	45.98hl	43.57jm
	HL+Ethyl.	49.37ci	48.64ei	46.86gj	43.71jl	42.29kn	40.33mn
	CL	50.08bi	49.81bi	46.10gk	42.02ln	41.00mn	40.08mn
	CL+Ethyl.	50.57ah	48.23fi	45.64il	43.34jm	40.06mn	37.96n
	$LSD_{5\%}$: St. Dur.: 1.5526 **St. Dur. × Trt.:** 3.8031 **Trt.:** 1.5526						
Chroma (*C)**	**BS**	26.81kl	26.68kl	29.87hk	36.05ae	37.83ad	39.20a
	BS+Ethyl.	26.55kl	27.13kl	27.69kl	32.43fi	35.36bg	38.39a
	HL	27.50kl	28.26jl	29.33ik	33.81eg	34.61dg	36.93ae
	HL+Ethyl.	26.62kl	28.36jl	28.45jl	33.84eg	34.67cg	35.86af
	CL	25.54l	27.46kl	31.92gj	35.33bg	38.32ad	38.48ab
	CL+Ethyl.	26.18kl	29.61ik	31.86gj	37.06ae	35.91af	33.56eh
	$LSD_{5\%}$: St. Dur.: 1.535 **St. Dur. × Trt.:** 3.7599 **Trt.:** 1.535						
Hue angle (*h*°)	**BS**	115.61a	111.11a	96.77be	84.02eh	67.35hn	60.64jq
	BS+Ethyl.	115.28a	101.44ad	84.24eh	74.64gj	67.74hm	65.48io
	HL	113.56ab	104.70ac	87.19dg	75.28gj	63.31ip	53.56lq
	HL+Ethyl.	112.31ab	92.51cf	70.73gl	57.98jq	50.42mq	48.17oq
	CL	78.95fi	72.44gk	56.81kq	49.73nq	47.61oq	45.27q
	CL+Ethyl.	79.11fi	63.98ip	52.83mq	49.58nq	46.32pq	45.09q
	$LSD_{5\%}$: St. Dur.: 6.0791 **St. Dur. × Trt.:** 14.891 **Trt.:** 6.0791						
Total soluble solids (TSS) (%)	**BS**	4.10ae	4.10ae	3.90be	3.97ae	4.10ae	3.87ce
	BS+Ethyl.	4.00ae	3.90be	3.87ce	3.93ae	4.00ae	3.87ce
	HL	4.23ab	3.97ae	4.13ad	4.03ae	4.00ae	3.83de
	HL+Ethyl.	4.13ad	4.27a	3.93ae	3.77e	3.90be	4.03ae
	CL	3.93ae	3.97ae	4.03ae	4.07ae	4.10ae	4.20ac
	CL+Ethyl.	3.90be	3.97ae	3.97ae	4.07ae	4.13ad	4.20ac
	$LSD_{5\%}$: St. Dur.: 0.11 **St. Dur. × Trt.:** 0.2695 **Trt.:** 0.11						
Titratable acidity (g citric acid kg^{-1})	**BS**	5.50cd	4.13fj	3.50ik	3.30jk	3.20jk	3.17jk
	BS+Ethyl.	3.87fk	3.37ik	3.30jk	3.27jk	3.17jk	3.03jk
	HL	8.13a	6.93b	4.80cf	4.73dg	4.30ei	3.53ik
	HL+Ethyl.	7.93a	5.13ce	5.10ce	3.97fk	3.80gk	3.27jk
	CL	5.70c	5.17ce	4.33ei	3.80gk	3.80gk	3.63hk
	CL+Ethyl.	4.73dg	4.57dh	3.80gk	3.47ik	3.40ik	3.40ik
	$LSD_{5\%}$: St. Dur.: 0.3308 St. Dur. × **Trt.:** 0.8102 **Trt.:** 0.3308						
Fruit firmness (N)	**BS**	13.20a	12.37ae	11.54bf	10.54fh	7.45jl	6.83km
	BS+Ethyl.	12.47ad	11.89bf	11.42bg	9.92gi	7.50jl	6.11ln
	HL	12.63ac	11.37bg	8.63ij	6.87km	5.38mo	4.43op
	HL+Ethyl.	12.36ae	10.89eg	9.30hi	6.83km	4.85np	3.52p
	CL	12.66ab	10.86eg	10.61fh	7.58jl	6.72km	4.16op
	CL+Ethyl.	12.62ac	11.07cg	10.98dg	7.76jk	4.51op	3.82p
	$LSD_{5\%}$: 0.544 **St. Dur.: St. Dur. × Trt.:** 1.3324 **Trt.:** 0.544						
Amount of unmarketable fruit (%)	**BS**	0h	0h	0h	8.06gh	19.25df	30.40bc
	BS+Ethyl.	0h	0h	0h	13.94fg	23.40ce	34.78b
	HL	0h	0h	0h	13.40fg	20.78df	30.40bc
	HL+Ethyl.	0h	0h	0h	4.84h	15.01fg	51.96a
	CL	0h	0h	0h	4.73h	15.98ef	25.50cd
	CL+Ethyl.	0h	0h	1.23h	3.09h	15.51fg	45.48a
	$LSD_{5\%}$: St. Dur.: St. Dur. × Trt.: Trt.:						

*: Means with different letters are statistically significant at P≤0.05 according to Duncan's multiple range test; [†]BS: Beefsteak; BS+Ethyl.: Beefsteak+Ethylene; HL: Heirloom; HL+Ethyl.: Heirloom+Ethylene; CL: Cluster; CL+Ethyl.: Cluster+Ethylene; LSD: Least significant difference; St. Dur.: Storage duration; St. Dur. × Trt.: Storage duration × Treatments; Trt: Treatments

Table 2- Effect of ethylene on weight loss, color (*L, *C**, *h*°) and total soluble solids contents of different types of tomatoes under shelf life at 20 °C**

Parameters	*Treatments*	*Storage duration (Days)*					
		0	**7+3**	**14+3**	**21+3**	**28+3**	**35+3**
Weight loss (%)	**BS**[†]	-	1.89ik*	1.98hk	2.34gk	2.40gk	3.84df
	BS+Ethyl.	-	1.30k	2.00gk	2.23gk	3.18eh	5.73bc
	HL	-	1.80jk	2.17gk	2.11gk	2.93gj	4.72cd
	HL+Ethyl.	-	1.64k	2.52gk	2.18gk	3.10ei	4.52d
	CL	-	2.97ej	3.76df	4.03df	7.60a	7.76a
	CL+Ethyl.	-	2.47gk	3.27eg	4.18de	6.43b	8.48a
	LSD$_{5\%}$: St. Dur.: 0.4315 **St. Dur. × Trt.:** 1.0569 **Trt.:** 0.4726						
Brightness (*L)**	**BS**	54.69a	52.23ac	50.95be	50.80be	47.13gn	45.30kr
	BS+Ethyl.	53.67ab	51.29bd	49.97ch	48.49dk	48.80dj	44.46mr
	HL	52.30ac	47.37fm	47.00gn	44.05nr	42.97qs	42.30rs
	HL+Ethyl.	49.37ci	48.34dk	45.86jp	44.72lr	44.07nr	42.76qs
	CL	50.08cg	47.76el	46.41ip	44.74lr	43.34ps	42.93qs
	CL+Ethyl.	50.57bf	48.11dk	46.81ho	43.61os	43.27ps	40.80s
	LSD$_{5\%}$: St. Dur.: 1.106 **St. Dur. × Trt.:** 2.7091 **Trt.:** 1.106						
Chroma (*C)**	**BS**	26.81l	31.63ik	33.70ei	34.00ei	33.99ei	37.62ac
	BS+Ethyl.	26.55l	30.25k	32.80gk	33.00gk	35.04ch	36.15bf
	HL	27.50l	31.55ik	32.35hk	33.34fj	33.67fj	40.02a
	HL+Ethyl.	26.62l	30.84jk	32.61hk	33.11fk	33.41fj	34.22di
	CL	25.54l	35.09ch	36.76de	35.82cf	37.23bd	38.94ab
	CL+Ethyl.	26.18l	34.77ch	35.76cg	37.11bd	37.23bd	34.21di
	LSD$_{5\%}$: St. Dur.: 1.028 **St. Dur. × Trt.:** 2.518 **Trt.:** 1.028						
Hue angle (*h*°)	**BS**	115.61a	78.95b	63.67ce	66.41ce	60.84df	47.60gi
	BS+Ethyl.	115.28a	83.13b	65.99ce	57.24eg	51.16fi	47.45gi
	HL	112.31a	82.95b	65.57ce	47.57gi	46.72gi	43.79hi
	HL+Ethyl.	113.56a	73.56bc	57.57dg	52.96fh	50.68fi	43.11hi
	CL	79.11b	60.72df	59.33df	51.00fi	44.06hi	41.93hi
	CL+Ethyl.	78.95b	68.29cd	57.60dg	44.10hi	43.07hi	41.22i
	LSD$_{5\%}$: St. Dur.: 3.7691 **St. Dur. × Trt.:** 9.2323 **Trt.:** 3.7691						
Total soluble solids (TSS) (%)	**BS**	4.10af	4.30ab	3.80gh	4.07bf	3.97ch	3.83fh
	BS+Ethyl.	4.00ch	4.03bh	4.00ch	4.13ae	3.90eh	3.87eh
	HL	4.23ac	4.10af	4.00ch	4.00ch	3.87eh	3.77h
	HL+Ethyl.	4.13ae	4.37a	4.10af	4.00ch	3.90eh	3.80gh
	CL	3.93dh	4.03bh	4.13ae	4.13ae	4.13ae	4.20ad
	CL+Ethyl.	3.90eh	3.77h	4.03bh	4.07bg	4.10af	4.13ae
	LSD$_{5\%}$: St. Dur.: 0.1149 **St. Dur. × Trt.:** 0.2815 **Trt.:** 0.1149						
Titratable acidity (g citric acid kg^{-1})	**BS**	5.50bc*	3.63fl	3.33hl	3.27il	3.07jl	2.90kl
	BS+Ethyl.	3.87ek	3.37hl	3.30il	3.27il	3.30il	2.80l
	HL	8.13a	5.37bd	4.33eh	4.23ei	4.10ei	3.80el
	HL+Ethyl.	7.93a	4.40eg	4.03ej	3.87ek	3.80el	3.37hl
	CL	5.70b	3.83ek	3.67fl	3.37hl	3.33hl	3.23il
	CL+Ethyl.	4.73ce	4.57df	3.80el	3.47gl	3.43gl	3.40hl
	LSD$_{5\%}$: St. Dur.: 0.3337 **St. Dur. × Trt.:** 0.8174 **Trt.:** 0.3337						
Fruit firmness (N)	**BS**	13.20a	9.35de	9.07de	8.93de	7.28gf	6.45gi
	BS+Ethyl.	12.47a	10.98b	8.50de	8.05ef	6.34gi	5.70hk
	HL	12.63a	6.07hj	5.93hj	4.61kn	4.59kn	3.29op
	HL+Ethyl.	12.36a	5.20jm	4.96jn	4.78kn	4.18mp	3.28op
	CL	12.66a	10.44bc	6.81gh	4.34lo	4.54ln	3.37op
	CL+Ethyl.	12.62a	8.50de	6.40gi	5.33il	3.92np	3.15op
	LSD$_{5\%}$: 0.459 **St. Dur.: St. Dur. × Trt.:** 1.1243 **Trt.:** 0.459						
Amount of unmarketable fruit (%)	**BS**	-	0e	0e	0e	33.33d	66.67b
	BS+Ethyl.	-	0e	0e	33.33d	33.33d	66.67b
	HL	-	0e	0e	0e	33.33d	33.33d
	HL+Ethyl.	-	0e	0e	0e	44.44c	66.67b
	CL	-	0e	0e	0e	33.33d	83.33a
	CL+Ethyl.	-	0e	0e	33.33d	44.44c	72.22b
	LSD$_{5\%}$: St. Dur.: 4.0581 **St. Dur. × Trt.:** 9.9403 **Trt.:** 4.4454						

*: Means with different letters are statistically significant at P≤0.05 according to Duncan's multiple range test; [†]BS: Beefsteak; BS+Ethyl.: Beefsteak+Ethylene; HL: Heirloom; HL+Ethyl.: Heirloom+Ethylene; CL: Cluster; CL+Ethyl.: Cluster+Ethylene, LSD: Least significant difference; St. Dur.: Storage duration; St. Dur. × Trt.: Storage duration × Treatments; Trt: Treatments.

Increases in weight losses with tomato ripening was reported by Sammi & Masud (2007) which was similar outcome obtained in this study. In this experiment ethylene treated fruit had higher weight losses as compared to control which agreed with the outcome of Dhall & Singh (2013) who expressed that ethylene treated tomatoes had more weight loss than control treatment. They mentioned that this increases in weight loss may be due to the rise in respiration rate during ripening.

3.3. Fruit color (L, C*, h°)*

The *L** values tended to decline with time in cold storage and shelf life. In general, ethylene treatment in tomato fruit resulted in lower *L** values than the untreated ones. The interactions between storage duration and treatments were significant under cold storage and shelf life at P≤0.05. After cold storage, the highest L^* value (50.18) was in control beefsteak whereas the lowest L^* value (37.96) was in ethylene treated cluster tomatoes after 35 days storage (Table 1). At the end of shelf life, maximum L^* value (45.30) was in untreated beefsteak tomatoes and minimum (40.80) L^* value was in ethylene treated cluster tomatoes treated after 35+3 days storage (Table 2).

Decrease in L^* values with storage extension of tomatoes were reported by Fagundes et al. (2015). According to these researchers the decrease in L^* values may be due to increase in the red color of tomatoes during storage. Camelo & Gomez (2004) mentioned that as the red pigmentation of tomatoes started to synthesize the L^* values showed decrease and had attained the dark red color.

Interactions between storage duration and treatments were statistically significant at P≤0.05. After cold storage, the highest C^* value (39.20) were in control beefsteak tomatoes and ethylene treated cluster tomatoes had the lowest C^* value (33.56) (Table 1). After shelf life, maximum C^* value (40.02) was in untreated heirloom tomatoes while minimum C^* value (34.21) was in ethylene treated cluster tomatoes (Table 2).

In the current study, different types of tomato exhibit increase in C^* values which was supported by the findings of Davila-Avina et al. (2011) who reported rise in C^* value throughout storage of tomatoes. Camelo & Gomez (2004) revealed that C^* had not been a good indicator to signify the ripening of tomatoes. However, it can be used as a suitable parameter for acceptance of consumers regarding tomatoes that are fully ripe.

In general, ethylene treated tomatoes had lower $h°$ values than untreated ones and prolonging storage duration decreased $h°$ values. After cold storage maximum $h°$ value (65.48°) occurred in ethylene treated beefsteak type with minimum $h°$ value (45.09°) in ethylene treated cluster tomatoes (Tables 1). After shelf life, highest $h°$ value (47.60°) occurred in control beefsteak type, while the lowest $h°$ value (41.22°) was in ethylene treated cluster tomatoes (Table 2).

Decreases in $h°$ values of tomatoes with extending storage duration was found by Chomchalow et al. (2002) as obtained from this study. Cantwell (2010) reported that the lower the $h°$ values the redder will be the fruit. Tomatoes attained red color with increase in storage and cluster type tomatoes was redder as compared to beefsteak and heirloom types in our study.

3.4. Total soluble solids (TSS)

TSS content in beefsteak and heirloom types decreased during storage but increased in cluster type fruit. After cold storage, highest TSS content (4.20%) occurred in both control and ethylene treated cluster type with lowest TSS content (3.83%) in control heirloom fruit (Table 1). At the end of shelf life period, maximum TSS content (4.20%) was in control cluster fruit while minimum TSS content (3.77%) was in control heirloom type tomatoes (Table 2).

Davila-Avina et al. (2011) expressed that tomato fruit harvested at pink maturity stage showed a decrease in TSS content during storage that agreed with our results regarding beefsteak and heirloom type of tomatoes however it contradicted with cluster type of tomatoes which exhibited increase in TSS content. Similar findings regarding cluster type of tomatoes were reported by Dhall & Singh (2013). They stated that this rise could be because of water loss, hydrolyzation of starch and other polysaccharides to soluble forms of sugar. However, their results contrasted with our findings for heirloom and beefsteak type of tomatoes which had a slight rise in TSS content at first and then decreased by the end of both cold storage and shelf life period. Increase in TSS content of cluster type of tomatoes with extending storage duration was reported by Mohammed et al. (1999).

3.5. Titratable acidity (TA)

The extension in storage duration considerably decreased the TA in cold storage and shelf life conditions. Ethylene treated tomatoes had lower TA than untreated ones. At the end of cold storage, the highest TA (3.63 g citric acid kg^{-1}) was exhibited by control cluster type whereas the lowest TA (3.03 g citric acid kg^{-1}) was recorded in ethylene treated beefsteak type of tomatoes (Table 1). At the end of shelf life period, the maximum TA (3.80 g citric acid kg^{-1}) was found in control heirloom type while minimum TA (2.80 g citric acid kg^{-1}) was found in ethylene treated beefsteak type of tomatoes (Table 2).

Decrease in TA with extension in storage duration was exhibited by different types of tomato in this study which agreed with the findings of Tigist et al. (2013) who stated that TA decreased with extension in storage. The reasons for decline in TA during our experiment can be due to the loss of citric and malic acid during ripening as reported by Sammi & Masud (2007) or it may be because of triggering of ethylene production that influence the organic acids and total soluble solids in tomatoes and other climacteric fruit as mentioned by Guilen et al. (2007).

3.6. Fruit firmness

Different types of tomatoes had a decline in fruit firmness with prolonging storage period. In general ethylene treated tomatoes had lower fruit firmness than non-treated tomatoes. Significant interaction between the storage duration and treatments existed at $P \leq 0.05$. At the end of cold storage, the untreated beefsteak type of tomatoes had maximum fruit firmness (6.83 N) while minimum fruit firmness (3.52 N) was determined in ethylene treated heirloom type of tomatoes (Table 1). At the end of shelf life period, the highest fruit firmness (6.45 N) was exhibited by control beefsteak type whereas lowest fruit firmness (3.15 N) was displayed by ethylene treated cluster type of tomatoes (Table 2).

Dhall & Singh (2013) revealed that ethylene treated tomatoes had less fruit firmness than control fruit as obtained in our study. Nyalala & Wainright (1998) expressed that storage of tomatoes at high temperatures result in lower fruit firmness than those stored at low temperatures which can be because of increased activity of polygalacturonase at 20 °C as mentioned by Kapotis et al. (2004). These findings agreed with more decrease in fruit firmness of tomatoes in the shelf life period than cold storage in this study.

3.7. Amount of unmarketable fruit

Quantity of unmarketable fruit increased with time in storage and shelf life. Ethylene treatment resulted in more unmarketable fruit than in controls apart from cluster tomatoes after shelf life. Significant interaction ($P \leq 0.05$) between storage duration and treatments occurred. At the end of cold storage, maximum 51.96% of unmarketable fruit occurred in ethylene treated heirloom tomatoes whereas minimum unmarketable fruit (25.50%) was in control cluster type of tomatoes (Table 1). At the end of shelf life, the most unmarketable fruit (83.33%) was in control cluster fruit with the least (33.33%) was in control heirloom fruit (Table 2).

Our results regarding higher unmarketable fruit in ethylene treated tomatoes during cold storage was supported by Geeson et al. (1986). They reported that ethylene treatment had enhanced decay development in tomato however this outcome contradicted with results of shelf life where control cluster type of tomatoes had highest unmarketable fruit. According to Cheng & Shewfelt (1988) storage of tomatoes at 4 °C for 15 days and then ripening at ambient temperature increased ethylene production and vulnerability to decay which support our findings of higher amount of unmarketable fruit during shelf life as compared to cold storage. According to Gonzalez-Aguilar et al. (2010) CO_2 and ethylene productions are vital components which determine the level of decay development in fruit and vegetables.

4. Conclusions

The conclusion drawn from the results obtained is that cluster type tomatoes were recorded to be more sensitive to ethylene treatment than beefsteak and heirloom types as they had produced the highest ethylene during cold storage. Beefsteak type tomatoes retained better postharvest quality than heirloom and cluster types of tomatoes at the end of cold storage and shelf life. Ethylene treatment resulted in higher ethylene production, weight loss with lower fruit firmness. At the end of cold storage, minimum ethylene production, respiration rate and maximum L^*, C^*, fruit firmness were found in control beefsteak type. Ethylene application in beefsteak type resulted in maximum $h°$ value. The highest titratable acidity and lowest amount of unmarketable fruit were noticed in control cluster type of tomatoes. At the end of shelf-life period; minimum weight loss and maximum L^*, $h°$, fruit firmness was noted in control beefsteak type. The lowest amount of unmarketable fruit and highest titratable acidity was obtained in control heirloom type. The highest total soluble solids contents were observed in control cluster type of tomatoes. Variations among the different types of tomato existed which can be taken into consideration prior to storage by the commercial growers, storage operators and wholesalers.

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