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Assessment of Physico-chemical Characteristics of Tomato (*Solanum lycopersicum*) Stored under Diffusion Channel System

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Abstract

A study was conducted to extend the shelf-life of tomato by diffusion channel system at the Institute of Agriculture, Visva-Bharati University, Sriniketan, West Bengal during 2010–12. Diffusion channel length 60, 120, 180 and 240 mm and diameter 3, 6, 9 and 12 mm were tested. The storage chambers of two liters capacity made of polyethylene tetrachloride were used. Tomato samples of 800±20 g at breaker stage were taken in each chamber and stored at 10, 20 and 30 °C. Quality characteristics such as physiological loss in weight (PLW), visual quality index (VQI), firmness, total soluble solids (TSS), titratable acidity, total sugars, ascorbic acid, lycopene and colour change (ΔE) were tested before and after storage to distinguish the relative changes. The stored tomato attained market acceptability after 40, 32 and 23 days at 10, 20 and 30 °C respectively under diffusion channel system. Minimum PLW of 3.37–3.74%, highest VQI number of 6.9–7, maximum firmness of 90–94N, titratable acidity as high as 0.46–0.48%, ascorbic acid content as low as 22.97 mg 100 g^{-1}, lycopene formation as low as 2.58–2.62 mg 100 g^{-1}, minimum ΔE of 29.87, TSS of 5.32–5.87 °Brix and total sugar content of 3.31–3.71 g 100 g^{-1} were recorded in chambers with diffusion channel length 180 mm and diameter 9 mm at 10 and 20 °C. Firmness, acidity and ascorbic acid were found significant ($p \leq 0.05$) by temperature, channel length and diameter. Total sugars and lycopene content had a significant difference with temperature and channel diameter. Temperature had a significant effect on TSS but length and diameter of channel had no significant effect.

Keywords: Tomato, diffusion channel, controlled atmosphere storage, physico-chemical characteristics

1. Introduction

Tomato (*Solanum lycopersicum*) is a wonderful vegetable embraced incredible health promoting properties such as vitamins, minerals, carbohydrates, carotenoids, fiber, fat and protein. It has good source of lycopene that has been proved in decreased risk of cardiovascular disease and cancer including breast and prostate cancer (Agarwal and Rao, 2000). Since, it is highly perishable in nature encounters several problems in its transportation, storage and marketing. It has been reported that the loss of 20–50% between harvesting and consumption of fresh tomato in tropical countries (Pila et al., 2010). Therefore, an increase in postharvest life is really desirable to reduce losses during supply chain. Major physiological activity in the postharvest life of a produce is respiration. Respiration is considered to be a key process which brings physiological disorders such as ripening, senescence, decay, degradation of chlorophyll and subsequently deterioration in the normal course of time. Respiration involving the consumption of oxygen (O_2) for oxidative break-down of organic components into simple molecules such as carbon dioxide (CO_2), water, with concurrent release of energy and other intermediates which can be used by the cell for synthetic reactions (Kader et al., 1989). The rate of physiological disorders can be slowed in low temperature and modified atmospheric condition. Modified atmosphere can be achieved by the natural interplay between respiration rate of the produce and transfer of gases through the storage that lead to an atmosphere richer in CO_2 and poorer in O_2. This atmosphere can potentially reduce the rate of respiration of the produce (Zagory and Kader, 1988; Mahajan and Goswami, 2001; Fonseca et al., 2002). Several researchers (Klieber et al., 1996; Sozzi et al., 1999; Akbudak and Eris, 2004; Kudachikar et al., 2011; Ramayya et al., 2012; Majidi et al., 2014; Vunnam et al., 2014) have been conducted experiments on enhancing the shelf life of various fruits by altering the gas compositions. Polymeric films, used as packaging materials for modified atmosphere packaging (MAP) are limited to gas permeability. In general, the fresh produce in MAP consumes O_2 and liberates CO_2 results absence of O_2 that leads to anaerobic respiration. It accelerates senescence, off-flavour and spoilage of produce due to fermentation (Kader et al., 1989). The limitations associated with polymeric films could be solved by use of perforations which are related to diffusion channel.

Diffusion channel system works based on the principle of

Fick's first law of gas diffusion. It states that the gas flux moves from a region of higher concentration to a region of lower concentration, with a magnitude that is proportional to the concentration gradient. Diffusion channel is a hollow tube fitted in an airtight storage chamber in which fresh produce is stored. Diffusion of gases takes place through the tube due to the concentration gradient between inside and outside the storage chamber. This creates a modified atmosphere inside the chamber which is beneficial for the storage (Baugerod, 1980). As a result of respiratory activity of stored produce, concentration of O_2 will be decreased and CO_2 increased. This creates a concentration gradient between inside and outside the chamber. Due to the concentration gradient, O_2 diffuses from outside to inside and CO_2 diffuses from inside to outside the chamber through the tube. Thereby a steady-state level of gases is maintained that depends on mass of the produce, rate of respiration and rate of diffusion of the gases. The rate of diffusion of gases is dependent on the length and cross-sectional area of the channel/tube (Ratti et al., 1998; Stewart et al., 2005). The gas composition in the storage chambers could easily be altered by varying the dimensions of the diffusion channels. Diffusion channel is used due to its extreme structural simplicity, which provides great flexibility in the design of storage chamber and the materials used are considerably less expensive. The quality of stored produce is well maintained. Keeping in view of the above perspectives, the investigation on enhancing the shelf life of tomato under diffusion channel system has been undertaken. Evaluation of physico-chemical characteristics of tomato stored under diffusion channel system, a part of this study have been reported in this paper.

2. Materials and Methods

2.1. Sample preparation

The investigation on enhancing the shelf life of tomato using diffusion channel system was carried out at the Institute of Agriculture, Visva-Bharati University, Sriniketan, West Bengal (India) during 2010−12. The popular tomato variety namely *Roma* in the West Bengal was selected. The matured tomatoes at breaker stage of ripeness and uniform size were procured from a farmer field near Visva-Bharati University. Breaker stage is a definite break in color from green to tannish-yellow, green with orange locular tissue and pink on not more than 10% of the surface (Sammi and Masud, 2007). The harvested tomatoes were graded manually and washed in chlorinated water concentration of 100 ppm to remove adhering dirt on their surface.

2.2. Experimental setup

Diffusion channel made of fiber glass comprising inner diameter of 3, 6, 9 and 12 mm and length of 60, 120, 180 and 240 mm were selected based on the information available in the previous study (Ratti et al., 1998; Stewart et al., 2005). The storage temperatures viz., 10, 20 and 30 °C were selected. The storage chambers of two liters capacity made of polyethylene tetrachloride (PET) were used for conducting the experiments. The experimental setup (Figure 1) was fabricated in such a way that four holes were provided on the lid. A silicon septum was fitted in the first hole to facilitate the withdrawal of gas sample from the chamber for analysis. Brass nipples with rubber gaskets were connected in second and third holes and tightened with nuts. A rubber tube length of 200 mm were connected to these nipples and closed by pinch clips after purging gas. In the fourth hole, a conical shape hallow rubber cork was fitted. The diffusion channel required size was rigidly fixed in the rubber cork. The joints were crammed by melted paraffin wax to secure air tightness. The absence of air bubble ensured the air tightness of diffusion chambers. Tomato samples of 800±20 g were taken in each storage chamber and kept in selected temperature. The temperature was maintained throughout the storage period.

2.3. Bio-chemical analysis

To distinguish the relative changes in quality during storage under diffusion channel system, the bio-chemical characteristics such as total soluble solids (TSS), titratable

Figure 1: Experimental setup (diffusion channel system)

acidity, total sugars, ascorbic acid and lycopene were determined in the laboratory after storage and before storage at breaker stage. The bio-chemical characteristics of freshly harvested ripe tomato also were determined to compare with the stored tomato. Total soluble solids (TSS) can be used for estimation of concentration of sugar and it can be expressed in degree Brix. TSS in degree Brix was directly measured using Abbe hand refractometer (Model NI; ATAGO, Japan) by placing a drop of supernatant on the prism of refractometer. Total sugars, titratable acidity, ascorbic acid and lycopene were determined as per the methods described by Ranganna (1986).

2.4. Texture analysis

Firmness of fruit referred to as the degree of softening. It was measured in terms of force (Newton) required to penetrate into the fruit through skin. The fruit penetrometer (Model

FT 327) fitted with a cylindrical plunger probe of 11 mm diameter made of stainless steel was used for measurement of firmness. Average of two forces at two diametrically opposite positions on the circumference of each tomato was taken. The penetrating force depends on the softness of fruit tissues and it is directly proportional to the firmness. For safety point of view, the penetrating force should be more (Sozzi et al., 1999).

2.5. Surface colour analysis

The surface colour of the tomato was measured using Minolta colorimeter (Minolta Co. Ltd., Japan) under hunter lab system with observation angle of 45° (Helga et al., 1999). It provides a reading in terms of L^*, a^*, and b^* which describes chromaticity. L^* denotes measurement of luminance (lightness) on a scale ranging from zero (black) to 100 (white); a^* denotes degree of greenness when negative and degree of redness when positive; b^* denotes degree of blueness when negative and degree of yellowness when positive. These three values were recorded at three points on the circumference of the whole tomato fruits and the colour was computed by average of three measurements. The colour measurements were made on tomato before and after storage on three samples from each treatment. Reference colour values for the fresh samples, before storage (L_f^*, a_f^*, b_f^*) and colour values from stored samples (L_s^*, a_s^*, b_s^*) were employed in calculating the colour change (ΔE), as defined by McGuire (1992); Vunnam et al. (2014):

$$\Delta E=\sqrt{(L^*_f-L^*_s)2+(a^*_f-a^*_s)^2+(b^*_f-b^*_s)^2}$$

Where, ΔE is the total change in colour, L_f is the brightness value of fresh produce before storage, L_s is the brightness value of stored produce, a_f is the hue value of fresh produce before storage, a_s is the hue value of stored produce, b_f is the chroma value of fresh produce before storage and b_s is the chroma value of stored produce.

2.6. Visual quality index

Visual observations were made by a jury of five persons to evaluate the overall market acceptability of the tomato taking into account discoloration, over softening, chilling injuries, decay, rotting, mold growth and shrinkage. Visual quality index (VQI) on 9-point grading scale described by Klieber et al. (1996); Wrzodak and Adamicki (2007) were used. Time, in which the stored tomato attained overall market acceptability, was considered for the end of storage. The storage time of 40 days at 10 °C, 32 days at 20 °C and 23 days at 10 °C were confirmed under diffusion channel system. But, the tomato was stored upto 14 days at 10 °C, 12 days at 20 °C and 7 days at 30 °C under control.

2.7. Statistical analysis

All the quality characteristics were determined for five representative samples in triplicate and the average values were determined. Factorial completely randomized design using AGRESS software package ($p\leq0.05$) was applied to analysis the effect of different diffusion channel lengths, diameters and temperatures on quality of tomato.

3. Results and Discussion

The biochemical constitutions of tomato at breaker stage and freshly harvested ripe tomato were presented in Table 1. The results obtained on biochemical constitutes were confirmed with the findings reported by Moneruzzaman et al. (2008); Pila et al. (2010).

3.1. Visual quality index

Figure 2(a) shows the effect of different diffusion channel diameter, length and temperature on VQI at the end of storage. Highest VQI number (6.91–7) was recorded in chambers with diffusion channel diameter 9 and 12 mm and length 180 and 240 mm as compared to other treatments. In control it was 5.42–5.97. The effect of temperature, diameter and length of channel on VQI was found significant at ($p\leq0.05$) while interaction effect was not significant. The results were supported by the study made by Wrzodak and Adamicki (2007) for tomato under controlled atmosphere storage.

Table 1: Physico-chemical characteristics of breaker stage and freshly harvested ripe tomato

Parameters	Breaker stage tomato	Freshly harvested ripe tomato
Firmness (N)	135.964	54.193
Total soluble solids (°Brix)	4.571	6.541
Titratable acidity (%)	0.655	0.422
Total sugars (g 100 g^{-1})	2.627	4.845
Ascorbic acid (mg 100 g^{-1})	15.760	34.535
Lycopene (mg 100 g^{-1})	0.947	5.215
Colour value		
L*	57.452	36.822
a*	-1.372	26.843
b*	12.651	21.781
ΔE	0.00	36.125

Each observation is the average of three replicates

3.2. Physiological loss in weight

Under the diffusion channel system, the PLW was found to be low compared to control. The PLW (%) was higher at 30 °C followed by 20 °C and 10 °C irrespective of the treatments (Figure 2b). The mean PLW was 3.1, 3.68 and 5.11% at 10, 20 and 30 °C respectively but 4.11, 6.51 and 9.45% in control. High mean PLW of 4.41 and 4.05% was recorded in the chambers equipped with channel diameter 3 mm and length 60 mm. At the same time, low weight loss of 3.37 to 3.74% was recorded in the chambers equipped with channel diameter 9 and 12 mm and length 120 mm. Low O_2 in storage chambers turn to decrease the respiration rate thereby delayed physiological changes (Koca et al., 1993). Effect of temperature, diameter and length of diffusion channel on PLW was found statistically significant (p≤0.05). The results obtained from this study were in conformation with the results reported by other authors (Kudachikar et al., 2011; Ramayya et al., 2012; Vunnam et al., 2014).

3.3. Firmness

Effect of temperature, diameter and length of channel on mean firmness (N) of stored tomato at end of storage period is presented in Figure 2(c). Highest firmness ranges between 89.34 and 94.05 N was recorded in the chambers equipped with channel diameter 9 and 12 mm and length 180 and 240 mm. Average firmness of 89.24 and 80.03 N were recorded at 10 and 30 °C respectively but it was 57.37 to 68.35 N in control. More firmness was observed while increasing length and diameter of channel and decreasing in temperature. This may be due to less diffusion of O_2 taking place in chambers equipped with higher length of channel. Hence, there is decreased respiration rate and slowdown ripening process. Higher CO_2 concentration results in suppression of the degradation of protopectin to soluble pectin thus reducing fruit softening (Klieber et al., 1996). Effect of temperature, diameter and length of channel on the firmness was found to be significant at (p≤0.05) but interaction effects were not significant. Thus, the channel diameter of 9 mm and length of 180 mm at 10 and 20 °C was adjudged to be best as it was maximum firmness. The results were consistent with findings of Wrzodak and Adamicki (2007); Kudachikar et al. (2011); Majidi et al. (2014); Vunnam et al. (2014).

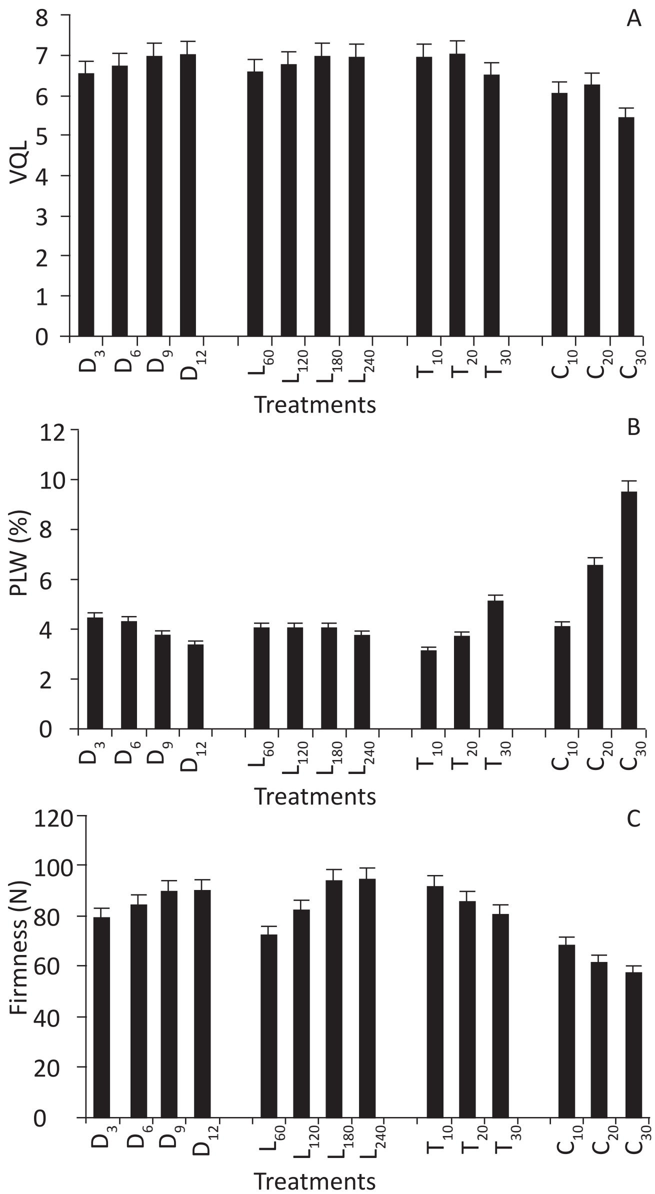

Figure 2: Effect of different treatments on (a) visual quality index (VQI) (b) physiological loss in weight (PLW) and (c) firmness of tomato at the end of storage (Error with 5% value)

3.4. Total soluble solids

The TSS was observed in the range of 5.32–5.87 °Brix at the end of storage period irrespective of the treatments, whereas it was 5.3 to 6.4 °Brix in control (Figure 3a). However, the TSS of 6.54 °Brix was measured in fresh harvested ripe fruits of the same variety (Table 1). The reduction in TSS under diffusion channel system may be due to slight conversion of sugars. Statistical analysis showed that the effect of length and diameter of channel on TSS was not significant but temperature had significant variation. However, the results obtained in control were found to be significant (p≤0.05). These results were in agreement with results reported by Javanmardi and Kubota 2006; Majidi et al. (2014).

3.5. Titratable acidity

The sour taste of tomato is attributed mainly by citric and malic acids. Free amino acids such as glutamic acid play vital role of taste-enhancement. 'Sourness' closely correlates with titratable acidity. Generally, the level of acidity in the fruits decreases during ripening process. At the breaker stage, it was found 0.655% whereas fresh harvested red ripe 0.422% (Table 1). In diffusion channel system, the level of titratable acidity increased with increase in the diameter and length of diffusion channel (Figure 3b). When the diameter and length of channel was 9 and 180 mm respectively, the acidity level was as high as 0.46–0.48%. Beyond this level of diameter and length there was no appreciable change in titratable acidity. It was also observed that the acidity level decreased as temperature increased. This might be due to the rate of respiration that subsides at lower temperature (10 and 20 °C) compared to higher temperature (30 °C). Therefore, the conversion of acidity into sugars may be delayed thereby quick ripening was also delayed. At the same time, the acidity level in control was found 0.41–0.42%. The influence of temperature, diameter and length of diffusion channel on titratable acidity was found to be significant (p≤0.05) but the interaction effect had no significant influence. The results were supported by results of Majidi et al. (2014); Vunnam et al. 2014.

3.6. Total sugars

Degradation of starch during ripening is the causes of production of glucose and fructose that builds sweetness in fruits. The taste of a fruit depends on the total sugar content.

The total sugars of 2.63 g 100 g^{-1} at breaker stage and 4.85 g 100 g^{-1} at fresh harvested ripe stage were determined (Table 1). One of the main intentions of the study is to delay the degradation of the starch into glucose and fructose. Sammi and Masud (2007) also reported that the total sugars content in green and ripe tomato were 2.86 and 4.99 g 100 g^{-1} respectively. Total sugar content under diffusion channel system ranges between 3.31 and 3.71 g 100 g^{-1} but 4–4.9 g 100 g^{-1} in control. No appreciable change in total sugars by changing length of channel but decreasing trend was noticed with increasing diameter of the channel (Figure 3c). Moreover, it was observed that the changes in sugar content was significantly less in chambers with diffusion channel of 9 mm diameter and 180 mm length. This might be due to low O_2 level which controlled the respiration rate thus delaying degradation of starch into sugars (Tasdelen and Bayindirli, 1998). Effect of individual treatments such as diameter of the channel and temperature were found significant ($p \leq 0.05$) statistically but channel length was not significant. However, the interaction effect between these three parameters was not significant. The results were in conformation with the findings reported by Tasdelen and Bayindirli (1998); Kudachikar et al. (2011).

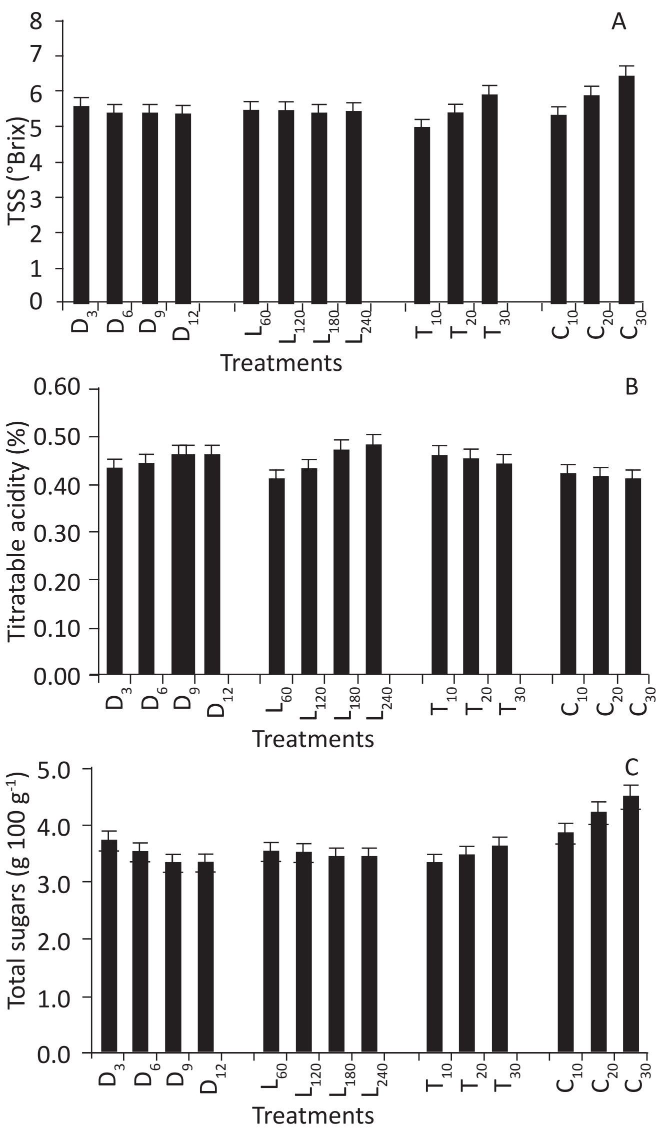

Figure 3: Effect of different treatments on (a) total soluble solids (TSS) (b) titratable acidity and (c) total sugars of tomato at the end of storage (Error with 5% value)

3.7. *Ascorbic acid content*

Ascorbic acid (Vitamin-C) exhibits more at ripened fruits. Ascorbic acid content of 15.76 and 34.54 mg 100 g^{-1} at breaker and fresh harvested ripe stage tomato respectively were recorded (Table 1). The effect of different temperature, diameter and length of diffusion channel on ascorbic acid content of tomato at the end of storage is shown in Figure 4(a). The ascorbic acid content was recorded slightly low with increase in diameter and length of channel but no appreciable decrease beyond the channel diameter and length of 9 and 180 mm respectively. At the same time it increased with increase in the temperature. The level of ascorbic acid was less under diffusion channel system irrespective of the treatments as compared to control. The minimum ascorbic acid content of 22.87 to 23.33 mg 100 g^{-1} was recorded in chambers fitted with the channel diameter of 9 and 12 mm, channel length of 180 and 240 mm at 10 and 20 °C. The control had maximum ascorbic acid of 24.24, 28.47 and 31.17 mg 100 g^{-1} at 10, 20 and 30 °C respectively. This may be due to high CO_2 and low O_2 reduced the respiration rate, thus hindered the ripening rate, delaying ascorbic acid production. Effect of temperature, diameter and length of the channel were found slightly significant both at 5% level, whereas the effect of first order and second order interactions were found not significant. The results were in conformation with the results reported by Ramayya et al. (2012).

3.8. *Lycopene content*

Carotenoids, mainly lycopene, are responsible for red colour of tomato. Color changes during ripening are characterized by loss of chlorophyll and rapid accumulation of lycopene. The lycopene content of 0.95 and 5.22 mg 100 g^{-1} at breaker and fresh harvested ripe stage respectively was recorded (Table 1). Figure 4(b) shows the effect of temperature, diameter and length of diffusion channel on lycopene content of tomato. The lycopene content significantly decreased when increasing the channel diameter from 3 to 9 mm and channel length from 60–180 mm but beyond this level there was no much considerable change. On the other hand, significant increase was observed with increase in temperature. The lycopene ranges between 2.58 and 2.62 mg 100 g^{-1} was recorded in chambers fitted with the channel diameter of 9 and 12 mm and length of 180 and 240 mm at 10 and 20 °C but 3.27 mg 100 g^{-1} at 30 °C. In control, maximum lycopene content of 3.26, 3.58 and 3.85 mg 100 g^{-1} at 10, 20 and 30 °C respectively were recorded. The lycopene content of tomato stored under diffusion channel system was low as compared to control and fresh red ripe tomato. This may be due to formation of lycopene inhibited by low O_2 atmosphere storage under diffusion channel system. The low O_2 and temperature prevents the ethylene formation thus decreased lycopene production (Helyes et al., 2011). Effect of temperature and diameter of the channel on lycopene was found statistically significant at 5% level. However, the effect of first order and second order interactions were not significant. These results were consistent with findings of Tasdelen and Bayindirli (1998); Sozzi et al. (1999); Helyes et al. (2011).

3.9. Colour change

Appearance is one of the salient features of fruits and vegetables. It may be influenced by several factors of which colour is the most important that directly affects the consumer acceptability. Total change in colour (ΔE) indicates the deviation in reflection. Initial ΔE value for the fresh samples (breaker stage) was recorded as zero and ΔE for fresh harvested ripe red tomato 36.13 (Table 1). The effect of different temperature, diameter and length of channel on ΔE value is depicted in Figure 4(c). The ΔE value decreased

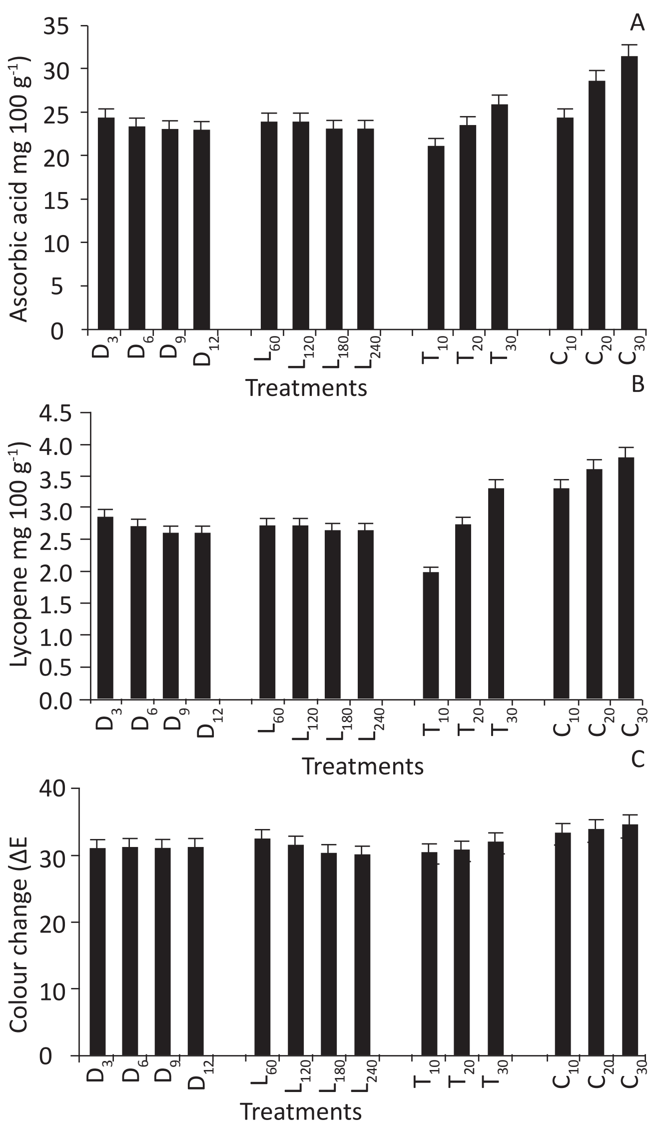

Figure 4: Effect of different treatments on (a) ascorbic acid (b) lycopene and (c) colour change (ΔE) of tomato at the end of storage (Error with 5% value)

from 32.30 to 29.87 when the channel length increased from 60 mm to 240 mm. Temperature had a little effect over the ΔE value (30.21 to 30.79). However, the channel diameter had no much influence over the ΔE value (30.78 to 31.05). In control, the ΔE value ranged between 33.23 and 34.22 that higher than tomato under diffusion channel system. The decrease in ΔE value indicates the slower rate of change in colour under diffusion channel system. This may be due to higher CO_2 and lower O_2 inhibits formation of lycopene that is main constituent of red pigment (Yang et al., 1987). The channel diameter of 9 mm, length of 180 mm and temperature of 10 and 20 °C delayed change in colour (ΔE) compared to other treatments. The temperature and channel length had a significant difference ($p \leq 0.05$) but channel diameter had no significant effect on colour change. The effects of first order, second order interactions and control were also not significant. The results of colour change (ΔE) were conformed to the findings reported by Vunnam et al. (2014).

4. Conclusion

The physico-chemical characteristics indicated that the tomato can be stored upto 40, 32 and 23 days at 10, 20 and 30 °C respectively under diffusion channel system (length:180 mm and diameter: 9 mm). But under control, 14, 12 and 7 days at 10, 20 and 30 °C respectively. Therefore, shelf life of tomato could be increased approximately 2–3 times when compared to control. Moreover, tomato stored under this system had better texture, harvest-fresh appearance, retained nutritional values and marketability conditions.

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