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Kinetics of Quality Changes in Tomatoes Stored in Evaporative Cooled Room in Hot Region

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A B S T R A C T

Performance of an Evaporative cooled (EC) room, built in hot and dry region of Punjab, was evaluated by storing the tomato fruits (var. *Naveen*) in it. Tomatoes were also stored in two other storage conditions, cold store (CS) and room conditions (RC). Average temperature and RH inside EC room during study was 26.5°C and 65-78%, respectively. The temperature and RH of RC and CS storage conditions were 25-41°C and 20-35%, and 10°C and 90%, respectively. Study observed that storage conditions affected PLW, TSS, colour and texture of fruits significantly ($p<0.05$). Physiological loss in weight (PLW) was determined as 16.91%, 10.38% and 5.95% in fruits stored at RC, EC room and CS storage, respectively. Overall, fruits stored at EC room and CS storage conditions delayed the quality deterioration of fruits in terms of PLW, colour and firmness. Fractional conversion kinetic model was found to be best fit to the experimental data on PLW, TSS, colour and firmness of stored tomatoes ($R^2 \geq 0.94$, random residual plots). Effect of storage temperature of studied storage conditions on all the quality parameters was described well by Arrhenius equation. Thus, these models would be useful in predicting the quality changes in tomatoes (var. *Naveen*) under storage conditions (RC, EC room and CS) of present study.

Introduction

India is the second largest producer of fruits and vegetables in the world. Although, the country has achieved heights in the production of fruits and vegetables, storage of these produce after harvest is still one of the most pressing problems. Most of the fruits and vegetables have very short life and are liable to spoil due to their high moisture content. Metabolism in fresh fruits and vegetables continues even after harvest also. Their deterioration rate increases due to ripening, senescence and unfavorable environmental factors. Therefore, preserving the fruits and vegetables in their fresh form demands that the chemical, bio-chemical and physiological changes should be restricted to a minimum by controlling the temperature and humidity of surrounding (Chandra *et al.*, 1999). It is evident from various sources that considerable volume of India's total fruits and vegetables is lost during postharvest handling in a year due to their short life (Nanda *et al.*, 2012). Therefore, being perishable, fruits and vegetables need immediate postharvest attention to increase their shelf life. It can be achieved by storing them at low temperature and high relative humidity (RH) conditions. Sub atmospheric temperatures and higher RH prevent the postharvest decay of many fruits and vegetables up to certain extent.

Many practices have been evolved to create cooler and humid environment for storage of fruits and vegetables. Storage clamps, root cellars, ventilated structures, evaporative cooled(EC) rooms etc. are considered to be the cost effective storage structures whereas refrigerated storage, controlled atmospheric storage, modified atmospheric storage, hypobaric storage etc. are considered to be hi-tech storage systems (Kale *et al.,* 2016). Selecting appropriate storage method for fruits and vegetables is critical, especially in developing countries where uninterrupted energy supply is not easily available. In present times, mechanical refrigeration system operated cold storage is found to be the most popular storage system. This system is able to achieve low (about 10°C) to very low (<0°C) storage temperatures. However, it is more energy intensive, involves substantial capital investment and requires uninterrupted supply of grid electricity which is not always readily available and cannot be easily installed in rural and remote areas. Energy efficient cold storage technologies are, therefore, required in India for on farm storage of fresh horticultural produce in remote and inaccessible areas to reduce losses. Low-cost, low-energy, environmental friendly cold rooms made from locally available materials and that utilize the principles of evaporative cooling were therefore developed in response to this problem. Such evaporative cooled (EC) rooms are able to maintain temperatures at 10–15°C below ambient and RH of 80-90%, depending on the season (Jha, 2008).

Various reports indicate that EC rooms have proved to be useful for short term, on-farm storage of fruits and vegetables in hot and dry regions (Jha and Chopra, 2006; Vala, 2016). These structures work on the principle of evaporative cooling which is an effective and economical means for reducing the temperature and increasing the RH of an enclosure i.e. storage room and has been extensively tried for enhancing the shelf life of horticultural produce (Jha and Chopra, 2006; Dadhich *et al.,* 2008; Odesola and Onyebuchi, 2009). EC room operates using induced processes of heat and mass transfer where water and air are working fluids (Camargo, 2007). It provides an inexpensive, energy efficient, environmentally benign (zero ozone depleting potential) and potentially attractive option for an on-farm storage of perishables (Zahra and John, 1996).

Although, volumes of reported information (Roy and Khurdiya, 1986; Jha, 2008; Vala *et al.,* 2016) is available on storage of various fruits and vegetables in EC rooms in different parts of India, literature reveals that no such report is available on the performance evaluation of EC room in hot and dry region of Punjab. Hot and dry region of Punjab (mainly South Punjab) is well known for production of various fruits like kinnow, guava, ber, aonla, pomegranate, plum, peach, pear etc. This region also produces substantial volume of tomato, potato, cabbage, cauliflower, capsicum, pumpkin, cucumber, water melon, chili etc. However, such huge horticultural produce fetches harsh climatic conditions during summer. Maximum ambient temperature in the region during summer (April-July) is reported as high as 50°C and RH is reported to be as low as 10%. Such climatic severity is usually accompanied by production of plum, peach, pear, tomato, capsicum, chili, water melons, cucumber, pumpkin etc. in the region during April-June. Consequently, these produce need effective means of storage to keep them fresh up to certain period of time. Theoretically, EC room is found to be the most suitable storage system in this region due to lower RH and intermittent supply of grid electricity in the region. Lower RH increases the wet bulb depression which ultimately helps to reduce the air temperature considerably.

By considering the importance of EC room as an appropriate farm level storage system, an attempt was made in present study to evaluate the performance of EC room in extending the shelf life of stored tomatoes in hot and dry region of Punjab. During study, freshly harvested tomatoes were stored in EC room built at ICAR-Central Institute of Postharvest Engineering and Technology (CIPHET), Abohar, Punjab (India). Another storage conditions were mechanical refrigeration system operated cold store (10°C) and room conditions with no cooling provided (25-41°C). The effects of storage conditions on selected quality parameters of tomatoes were evaluated in the study.

Materials and Methods

Experimental site

A study was conducted at ICAR-CIPHET, Abohar (Latitude 30° 09′N, 74° 13′E, 185.6 m above mean sea level), Punjab, India. This region falls in arid zone, having hot summers (May–July) and mild winters (December–February). The maximum temperature in summer reaches to 50°C whereas minimum temperature drops to 0°C in winter. During May-June, RH is considerable low (up to 10-15%) which supports the use EC rooms in storage of fruits and vegetables.

Storage conditions

The study was carried out to evaluate the effect of three different storage systems, namely EC room, cold store (CS) and ambient room conditions (RC), on storage life of tomatoes. EC room was a double walled, 3 m x 3m x 3m (inside) size structure with a total volume of 27 m^3. Walls were double layered with a 10 cm cavity in between them. This cavity was filled with river bed sand and water was circulated in the cavity using drip irrigation. Roof was made of RCC whereas floor was made of cement concrete. A water tank was kept on the roof of the structure to provide regular water supply. The capacity of EC room was two tonnes. The average temperature inside EC room during study was 26.5°C and RH varied from 65-78%. The Cold store (CS) temperature was kept as 10°C and RH was about 90%. The room temperature varied from 25-41°C (average temperature 33°C) and RH varied from 20-35%.

Stored material: tomato

The tomato is one of the most widely cultivated and consumed fresh vegetables in the world. It is extensively used in food industries as raw material for making of different foodstuffs. It is cultivated throughout India and is available almost throughout the year. It is also one of the most cultivated vegetables in hot and dry region of Punjab. However, it has lower shelf life if harvested under ripe conditions. Therefore, tomatoes were selected as a representative vegetable during study.

Quality parameters of stored tomatoes

Mature fruits of tomato, variety "*Naveen*" [*soluble solids 6-7 %; moisture content 90±2% (wb)]* at the red ripe stage grown under the insect proof net house (60 mesh size) of ICAR-CIPHET, Abohar were selected. The fruits were sorted followed by washing in running tap water to remove soil and other adhering dust particles. Tomatoes were kept in plastic crates and stored in three different storage systems till further use. 5 kg sound fully ripe tomato samples were selected for each treatment. The samples were stored for a period of 15 days and were analysed for physicochemical parameters on regular basis at an interval of 24 hours to assess the effectiveness of EC room in comparison to CS or RC. Physiological loss in weight (% PLW), total soluble solids (°Brix), color attributes and texture were evaluated using standard protocols. PLW was calculated using following formula (Eq.1).

$$PLW\ (\%) = \frac{W_1 - W_i}{W_1} \times 100 \quad (1)$$

Where, W_1 is the initial weight of the sample, W_i is the weight of the sample during storage, i takes the value of storage days with values 1, 2, 3, … 15.

Instrumental color of the samples in terms of L*, a*, b* values of CIE system were recorded by using a pre-calibrated handy colorimeter (NR-3000, Nippon DenshokuInd Co Ltd, Japan). L* indicated lightness, a* chromaticity on green (−) to red (+) axis, and b* chromaticity on a blue (−) to yellow (+) axis. The total color difference (ΔE) was calculated using following equation (Eq.2).

$$\Delta E = \sqrt{(L^*_{sample} - L^*_{ref})^2 + (a^*_{sample} - a^*_{ref})^2 + (b^*_{sample} - b^*_{ref})^2} \quad (2)$$

The fresh samples were used as a reference (called as “ref”) sample.

Total soluble solids (ºBrix) of tomato samples were measured with hand held refractometer (Atago, Japan). Texture of the tomato fruits was determined in terms of fruit firmness using texture analyser (Model *TA+Di*, Stable Micro Systems, UK) at an interval of 24 h. Probe of 5 mm diameter (P/5S)was used during test. Five fruits from each storage condition were punctured during test and peak force required to puncture the fruit was noted. Penetration depth was kept as 10 mm. Fruit firmness was the average peak force (N) measured for five fruits. Pre-test speed, test speed and post-test speed were 2 mm/s, 1 mm/s and 10 mm/s, respectively. Firmness was determined after keeping the fruits at room conditions for 1h in order to avoid the effect of storage temperature on determination. Fifteen measurements were recorded from 5 fruits of each storage condition. A fractional conversion kinetic model (Eq.3) was used to model the changes in PLW, TSS, ΔE (total color difference), a*(redness) and firmness of tomatoes, due to different storage conditions (Pinheiro *et al.*, 2013).

$$\frac{C - C_{eq}}{C_0 - C_{eq}} = e^{-kt} \quad (3)$$

Where, C is the observed quality parameter (PLW, TSS, ΔE, a*and firmness), subscript‘0’ indicates the initial value of quality parameters, subscript ‘eq’ indicates equilibrium value, t is storage time, and k is the rate constant at temperature T (in K). The temperature dependence of the reaction rate (k) was described by an Arrhenius type equation as shown by Eq.4 (Pinheiro *et al.*, 2013).

$$k = k_{ref} \exp\left[\frac{-Ea}{R}\left(\frac{1}{T} - \frac{1}{T_{ref}}\right)\right] \quad (4)$$

Where $k_{ref}$is the reaction rate constant at reference temperature (T_{ref}), Eais the activation energy (J/mol), R is the universal gas constant (8.314 J/mol-K), and T is the absolute temperature (K). The reference temperature was the average temperature at room conditions (T_{ref} = 306 K).

Results and Discussion

Study evaluated the performance of EC room built in hot and dry region by storing tomato fruits for 15 days. For comparison purpose, tomatoes were also stored simultaneously at RC and CS storage conditions for a storage period of 15 days. Various results obtained are summarized in Table 1 and Figure 2. Results (Table 1 and Fig. 2) revealed that storage conditions significantly affected ($p<0.05$) the selected quality parameters of stored tomatoes. Quality of tomatoes deteriorated with storage period but the severity of deterioration was governed by the storage conditions, especially the temperature (Table 1).

Effect of storage conditions on quality parameters of stored tomatoes

With storage period, PLW of stored fruits increased significantly ($p<0.05$) in all the storage conditions (Fig. 2a). However, its value was higher for RC storage (16.91%) as compared to EC room storage (10.38%) and CS storage (5.95%). Such difference in PLW might be due to higher moisture loss at RC compared to other two storage conditions (Pinheiro *et al.,* 2013). Rate of moisture loss depends on the temperature and RH of the storage environment. Similarly, Javanmardi and Kubota (2006) and Getinet *et al.,* (2008) reported that the main reason behind weight losses in stored tomato fruits at room temperature storage is the higher transpiration rate. CS and EC room provided higher RH, 90% and 65-78% respectively, compared to RC (20-35%). Generally, 10% PLW is considered to be the end point of the shelf life of fresh fruits and vegetables (Pal *et al.,* 1997). On this basis, tomatoes stored at RC storage reached shelf life end point on 8^{th} day (10.59% PLW), tomatoes stored at EC room conditions reached shelf life end point on 15^{th} day (10.38% PLW) whereas fruits stored at CS conditions were still fresh (5.95% PLW).

A fractional conversion kinetic model was fitted to the experimental data and estimated parameters were presented in Table 2 and Table 3. Results (Table 2 and 3) indicated that this model was found to be best fit to the PLW data with coefficient of determination (R^2) as ≥0.98. Residual plots were random for EC room and CS storage whereas it showed pattern for RC storage. Activation energy (Ea) for PLW was determined as 22.47 kJ/mol.

However, Pinheiro *et al.,* (2013) reported the activation energy for weight loss in tomato (var. *Zinac*) as 86.4 kJ/mol when tomatoes were stored at 2, 5, 10, 15 and 20°C. Such difference in activation energy might be attributed to the storage temperature.

Like PLW, TSS is also an important quality indicator of fruits. Results showed that TSS of tomatoes increased (7.97 to 19%) significantly ($p<0.05$) with storage period irrespective of the storage condition (Table 1). However, its increase was higher in RC storage (17%) and EC room storage (1.85%) as compared to CS (Fig. 2b). Generally, increase in TSS is associated with rate of metabolic activities of tomatoes which, in turn, is associated with storage temperature. Hence, tomatoes stored at RC had higher values of TSS due to higher temperature. Fractional conversion model found to be the best fit ($R^2 \geq 0.96$) to TSS experimental data (Table 2). Reaction rate constant (k_{ref}) and activation energy for changes in TSS were determined as 1.24×10^{-4} day^{-1} and 171.16 kJ/mol, respectively.

It is evident from results that colour of stored tomatoes was significantly ($p<0.05$) affected during storage. Lightness (L*) value and yellowness (b*) value of the stored tomatoes decreased whereas redness (a*) value increased with storage period at all storage conditions (Table 1). Reduction in L* value during storage indicates an increase of tomato darkening due to carotenoid synthesis (Yahia *et al.,* 2007). Decrease in lightness was more pronounced in the tomatoes stored at RC followed by EC room and CS.

Table.1 Initial and final values of selected quality parameters of tomato fruits

Quality parameter	Initial values	Final values		
		RC	EC room	CS
PLW (%)	0	16.91±3.11	10.38±2.17	5.95±2.04
TSS (°Brix)	6.4±2.1	7.62±1.24	6.83±2.11	6.51±2.62
Lightness (L*)	48.17±10.11	45.85±9.45	46.15±8.35	47.96±10.20
Redness (a*)	85.59±16.06	90.83±15.22	87.36±9.54	86.21±7.63
yellowness (b*)	38.06±7.21	30.03±5.32	35.19±6.23	37.21±12.31
ΔE	0	9.35±2.10	2.41±1.01	1.1±0.76
Firmness (N)	17.58±6.11	4.04±3.01	9.4±2.11	13.99±4.31

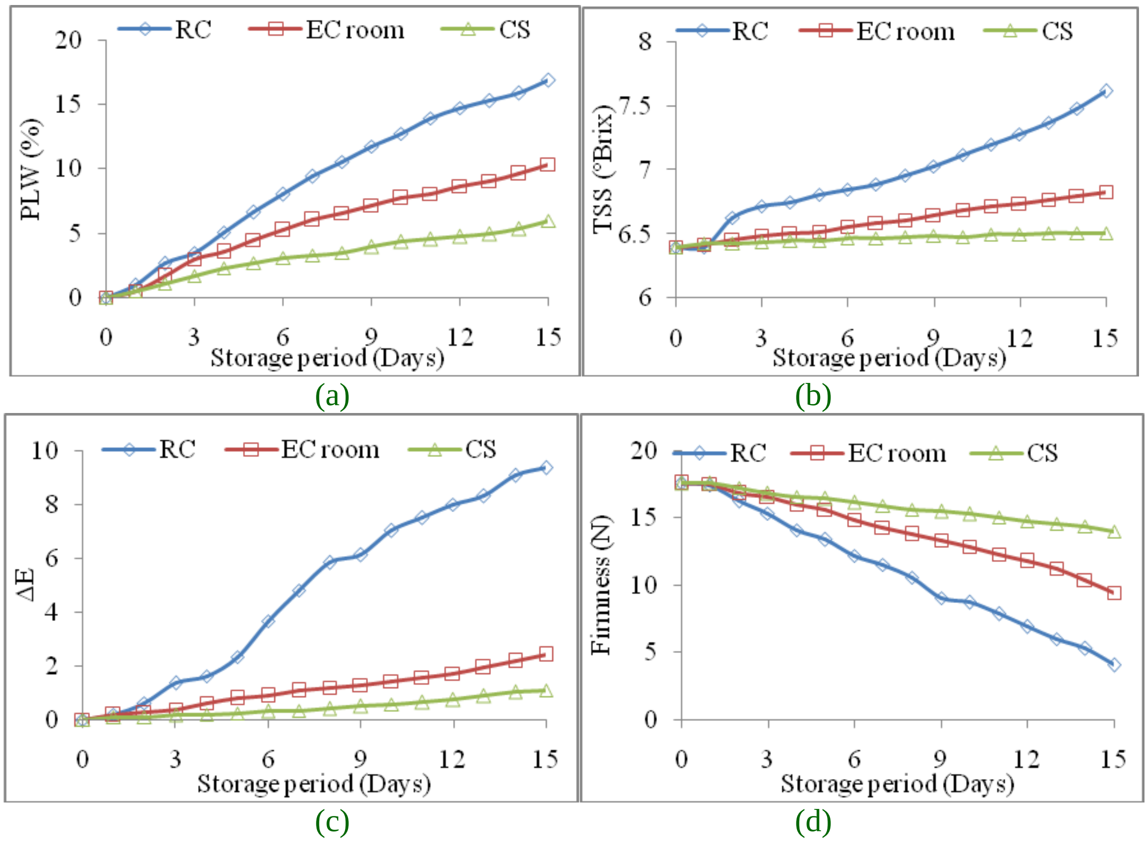
Table.2 Kinetic parameters for selected variables of tomato stored at different conditions

Variable	Storage condition	C_0	C_{eq}	k (day^{-1})	R^2	Residual plot
PLW	RT	0.92	79.12	0.016	0.99	Pattern
	ECC	0.51	22.3034	0.039	0.98	Random
	CS	0.47	12.9146	0.036	0.99	Random
TSS	RT	6.40	614.13	1.24E-4	0.97	Random
	ECC	6.40	1305.35	2.17E-5	0.98	Pattern
	CS	6.40	6.53802	0.109	0.96	Random
ΔE	RT	0.18	30620.5	2.06E-5	0.95	Random
	ECC	0.16	17451	7.70E-6	0.94	Random
	CS	0.08	16836.3	3.29-6	0.97	Random
a*	RT	85.81	20331.2	5.88-6	0.99	Pattern
	ECC	89.56	93.074	0.017	0.94	Random
	CS	81.41	1748.82	1.74E-5	0.97	Random
Firmness	RT	17.58	-18746	4.74E-5	0.96	Random
	ECC	17.58	-72386.8	6.79E-6	0.95	Random
	CS	17.58	-47.8622	3.66E-3	0.97	Pattern

Table.3 Activation energy for quality parameters of tomato due to storage

Variable	k_{ref}(day^{-1})	Ea (kJ mol^{-1})
PLW	0.016	22.47
TSS	1.24E-4	171.16
ΔE	2.06E-5	108.13
a*	5.90E-6	92.02
Firmness	4.74E-5	109.70

Fig.1 Effects of storage conditions on PLW



Redness value significantly ($p<0.05$) increased at all storage conditions. Redness (a* value) represents the tomato colour development from green to red during ripening. Thus, increase in a* value indicated that fruits became more reddish with storage. Total colour difference (ΔE), that combined the changes in all the three color attributes (*L**, *a** and *b**), increased with storage period in all storage conditions (Fig. 2c). But, this increase was more pronounced in RC as compared to EC and CS storage. After 15 days of storage, values of ΔE for fruits stored at RC, EC room and CS storage conditions were observed as 9.35, 2.41 and 1.10, respectively.Fractional conversion model was the best fit ($R^2 \geq 0.94$) to ΔE and a* data (Table 2). Activation energy to achieve changes in ΔE and a*during storage was determined as 108.13 and 92.02 kJ/mol, respectively.

Texture is considered to be the most important factor that determines the quality of stored tomatoes. Texture of stored tomatoes was determined in terms of firmness (N). It is evident from Fig.2d that initial firmness value of stored tomatoes was 17.58 N and it decreased with storage period. The highest decrease was observed in tomatoes stored at RC (77%) followed by EC room (46.53%) and then CS (20.42%). Thus, storage temperature could significantly ($p<0.05$) affect the firmness of tomatoes. Lower the temperature more was the firmness and vice versa. Results showed that firmness data of stored tomatoes was well described by an Arrhenius fractional conversion kinetic model. This model was found to be the best fit ($R^2 \geq 0.95$) to firmness data (Table 2). Activation energy to achieve changes in fruit firmness during storage was determined as 109.70 kJ/mol. However, literature reveals that reported data on activation energy required for tomato texture kinetics shows a wide variation. Activation energy required for textural changes in tomatoes was reported as 22.3 kJ/mol by Schouten *et al.*, (2007), 71.3 kJ/molby Van Dijk *et al.*, (2006), and 87.5 kJ/mol for outer pericarp and 94.8 kJ/mol for radial pericarp by Lana *et al.*, (2006). Such differences in activation energy underscore the variation in physiological behavior of tomato fruits that might be attributed to different maturity stage, cultivar (''*Bonavista*'', ''*Tradiro*'' and ''*Belissimo*'', respectively), storage temperatures and modeling approach.

From results, it can be summarized that lower temperature (moderate temperature in case EC room) and high RH of EC room and CS storage conditions did not accelerate the physicochemical changes and thus could preserve the freshness of tomatoes in terms of PLW, TSS, color and fruit firmness in a better way. Fractional kinetic conversion model was found adequate in describing the kinetics of PLW, TSS, color and firmness of stored tomato fruits. This model may be useful in predicting these quality parameters of tomato fruits during storage in EC room.

Tomato fruits were stored at three different storage conditions, namely room conditions (RC), EC room and cold store (CS). Study observed that storage conditions affected the PLW, TSS, colour and texture of tomato fruits significantly ($p<0.05$).Fruits stored at CS and EC room storage conditions showed a delay in quality deterioration in terms of PLW, colour and firmness. Tomatoes stored at RC storage reached shelf life end point on 8^{th} day whereas fruits stored in EC room required 15 days to achieve shelf life end point. PLW, TSS, colour and fruit firmness data of stored tomatoes fitted well to the fractional conversion kinetic model ($R^2 \geq 0.94$, random residual plots). Similarly, the Arrhenius type equation adequately described the temperature effect of different storage conditions on all quality parameters. Thus, these models would be useful in predicting the quality changes in tomatoes fruits (var. *Naveen*) under storage conditions (RC, EC room and CS) of present study. From study, it can also be concluded that EC room may a viable option to store tomato fruits (var. *Naveen*) for 15 days in hot and dry region if cold storage facility is not available or affordable.

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