Response of Polyethylene Packaging and Storage Temperature on Postharvest Physiology and Quality of Tomato

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ABDUL HAI RAHIMY

Thesis

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ABDUL HAI RAHIMY

2017

MAHARANA PRATAP UNIVERSITY OF AGRICULTURE & TECHNOLOGY
RAJASTHAN COLLEGE OF AGRICULTURE, UDAIPUR

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Dated: / /2017

This is to certify that **Mr. Abdul Hai Hahimy** had successfully completed the comprehensive examination held on 05/06/2017 as required under the regulation for the degree of **Master in Agriculture (Horticulture)**.

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Dated: / /2017

This is to certify that this thesis entitled **"Response of Polyethylene Packaging and Storage Temperature on Postharvest Physiology and Quality of Tomato"** submitted for the degree of **Master in Agriculture** in the subject of **Horticulture** embodies benefice research work carried out by **Mr. Abdul Hai Rahimy** under my guidance and supervision and that no part of this thesis has been submitted for any other degree. The assistance and help received during the course of investigation have been fully acknowledged. The draft of the thesis was also approved by the advisory committee on **17/02/2017.**

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ACRONYMS

S. No.	Symbol		Full name
1.	%	=	Per cent
2.	B:C ratio	=	Benefit : Cost ratio
4.	C.D.	=	Critical difference
5.	C.R.D.	=	Completely randomized design
6.	cv.	=	Cultivar
7.	d.f.	=	Degree of freedom
8.	*et al.*	=	(et alia) and elsewhere
9.	etc.	=	Etcetera
10.	Fig.	=	Figure
11.	g	=	Gram
12.	i.e.	=	(id est) that is
13.	M.S.S.	=	Mean sum of square
14.	Max	=	Maximum
15.	mg	=	Milligram
16.	Min	=	Minimum
17.	ml	=	Milliliter
18.	mm	=	Millimeter
19.	MPa	=	Mega Pascal
20.	N.S.	=	Non-significant
21.	NEB	=	Non-enzymatic browning
22.	nm	=	Nanometer
23.	No.	=	Number
24.	ºB	=	Degree brix
25.	ºC	=	Degree Celsius
26.	ppm	=	Part per million
27.	Q	=	Quintal
28.	R.A.	=	Regular atmosphere

Cont…..

S. No.	Symbol		Full name
29.	R.H.	=	Relative humidity
30.	S.Em.	=	Standard error of mean
31.	TA	=	Texture analyzer
32.	TSS	=	Total soluble solid
33.	viz.	=	(Videlicet) Namely

1. INTRODUCTION

Tomato (*Lycopersicon esculentum* L.; Solanaceae) is one of the most popular vegetables in the world. In India, area covered under tomato is 8.79 Lakh ha with the production of 21.2 MT. Major tomato producing states are Andhra Pradesh, Karnataka, Madhya Pradesh, Odisha, West Bengal, Gujarat and Bihar. In Rajasthan, tomato is grown over 15,510 ha with a production of 7,3570 MT and productivity of 4,757 kg ha^{-1} (Anonymous, 2014).

Nutritionally, tomato is a rich source of vitamins A, C and E, flavonoids, potassium and other mineral salts. It contains a high volume of water, thereby refreshing in salads on hot days and low in calories too, with around 14 Kcal $100g^{-1}$. It contains large amount of lycopene, an antioxidant which helps to mop up damaging free radicals in the body that can harm our cells, thereby consumption of tomato and its products significantly reduce risk of development of colon, rectal and stomach cancer (Kucuk, 2001).

Packaging of fruits is one of the most commonly used postharvest practice that puts them into unitized volumes which are easy to handle while also protecting them from hazards of transportation and storage (Burdon 2001). Packaging was used primarily to prevent food contamination with unwanted objects. However, consumer demand for desirable food quality has led to a surge in packaging innovation. For instance, Cha and Chinnan (2004) noted the increasing use of plastic films in food packaging, which combines the biophysical properties of plastic films with biopolymer coatings to maintain the nutritional and sensory quality of the product. Using plastic as packaging material also offers marketing advantage. Unlike metal and aluminium packaging materials, harnessing the transparency of film packaging for product visibility is now widely practiced, enabling consumers to assess the visual quality of the product prior to purchase. However, the variable permeability of plastics to light, gases and vapours is a major drawback.

In tomato, optimum storage temperature depends on the maturity or ripeness of fruit at harvest. Immature and mature green tomato is more sensitive to chilling temperature than pink or red tomato. If held for longer than two weeks below 10°C or for longer than 6-8 days at 5°C, they may develop chilling injury (CI). Mature green tomato can be stored up to 14 days between 12.5 and 15°C without major decreases in flavour or colour development, whereas immature-green fruit would be injured by that time-temperature combination (Hardenburg *et al.*, 1986). Firmness of 'Trust' tomato decreased during storage, particularly in fruit stored at 0, 15 or 20°C (Prolux *et al.*, 2001). After 7 days, tomato stored at 20°C was softer and the fruit flesh was jucier and pulper, whereas the epidermis was tougher (Auerswald *et al.,* 1999). Hue of 'Trust' tomato stored at 10, 15 or 20°C decreased during storage but remained stable in tomato stored at lower temperature. The decrease in hue value from about 74 to 45 degrees in those tomato corresponded to changes in the superficial color from reddish orange to dark red, exactly like the visual color changes observed during storage. Chroma of 'Trust' tomato fruit increased slightly during storage regardless of the temperature (Prolux *et al.*, 2001).

In India, different packaging materials and cold storage facility are rarely used for extending storage life of tomato fruits due to lack of facility of storage and absence of standard recommendations on packaging materials and storage temperature for tomato fruit. This is one of the major constraints faced by wholesalers and retailers. Likewise, studies on effect of packaging material and storage temperature have not been carried out on this vegetable.

Therefore, it is proposed to carry out the research work entitled, **"Response of Polyethylene Packaging and Storage Temperature on Postharvest Physiology and Quality of Tomato cv. Dev"** during 2017 with the following objectives

(i) To find out suitable polyethylene materials for packaging of tomato fruits.

(ii) To study the effect of storage temperature on postharvest physiology and quality of tomato fruits.

2. REVIEW OF LITERATURE

During storage many biochemical changes take place which are categorized as the postharvest changes. These changes determine the storage life of fruits. The knowledge generated as postharvest or storage methods can be relevant to evaluation of conventional methods for improving the quality and shelf life of tomato fruits which can make their availability throughout the year at different places.

The research work undertaken in the past in various fruits on different aspects *viz*., physico-chemical characteristics of fruits, shelf life, postharvest physiology, quality and sensory properties influenced by packaging material and storage temperature is briefly reviewed here under the following suitable heading:

2.1 Fruit composition and nutritional variability of tomato fruit

2.2 Physiological and biochemical changes during maturity and ripening in tomato fruit

2.3 Effect of packaging material on postharvest physiology and quality of tomato fruit

2.4 Effect of storage temperature on postharvest physiology and quality of tomato fruit

2.1 Fruit composition and nutritional variability of tomato fruit

Much of the data relating to tomato fruits are cultivar specific; however the information can be summarized to provide a general picture. The pulp of the fruit is of most importance in relation to nutrition. Some workers have investigated the composition of tomato fruit and biological activities. Tomato fruits have a high nutritive value, being a rich a source of minerals and organic acids tomato is good source of vitamins viz., Vitamin C, Vitamin A, Vitamin B_1 and Vitamin $B_{2.}$ 100 g of edible portion of tomato contains 94.1 g water, 1 g protein, 0.3 g fat, 4 g carbohydrate, 1100 IU Vitamin A, 0.2 Mg Vitamin B, 0.6 Mg nicotinic acid, 0.31Mg pantothenic acid, 23 Mg vitamin C, 0.27 Mg vitamin E, 390 Mg citric acid, 268 mg potassium, 27 mg phosphorus and 51 mg chlorine (Chatfield, 1959).

Red tomatoes contain 25 mg ascorbic acid/100g of tomatoes by weight. In this way, tomatoes are a valuable source of ascorbic acid that helps to protect our body from various diseases. Tomato can meet easily 40% of an adult's body requirement by providing 60mg of ascorbic acid and 2/3rd of the children's daily requirement that is about 40mg per day (Leoni and Jongen 2002).

Majority of the total antioxidant (48% lycopenc. 43% ascorbic acid and 53% phenolics) are located in the epidermis of the fruit (Toor and Savage, 2006). Vitamin C content in tomato fruit varies depending on the cultivars (Markovie *et al.*, 2002).

Tomato contains significant quantity of β- carotene that has vitamin A activity. This small amount of tomato can easily meet the 20% daily requirement of an adult's body. Some vitamins of the B group are also present in tomatoes among these vitamins; thiamine is present in concentration ranges from 60-120mg per 100g of ripe tomato and tomato juice. While riboflavin and niacin contents of the tomato are comparatively low, 20-50mg riboflavin per 100g of tomato. Lycopene is one of the most important carotenoid present in red tomato. Lycopene formation occurs at the last stage of tomato ripening. The other carotenes that are present in tomato are in lower concentration than that of lycopene, which is about 85% of total carotenoids. (Muhammad *et. al.,* 2015).

2.2 Physiological and biochemical changes during maturity and ripening in tomato

2.2.1 Weight loss

Pila *et al*. (2010) reported that after 10 days of storage at ambient temperature tomato fruit exhibited 6.50 per cent, 5.35 per cent and 6.78 per cent weight loss in GA_3 (0.1%). $CaCl_2$ (1%), $CaCl_2$ (1.5%), and SA (0.4mM) treated fruits. Respectively, while it reached to 19.89 per cent in untreated fruits. At 20th day of storage period, tomato treated with chlorine, packet in perforated polyethylene bag and kept in refrigerator showed minimum weight loss (4.9%), at 40th day, this loss was 85.86 per cent (Nasrin *et al.*, 2008).

Mutari and Debbie (2011) indicated that weight loss was found significantly higher at 20^0C than at 12^0C. Weight loss of tomatoes stored at room temperature was significantly higher than low temperature stored tomatoes, it was also found significantly higher during first 7 day at 12^0C (Javanmardi and Kubota, 2006). Continuous increase in weight loss (19.20%) was observed in control at ambient temperature during postharvest storage, while $CaCl_2$ (1%) treated fruit showed only 15.22 per cent weight reduction (Mujtaba and Masud, 2014).

One of the main problems during post harvest storage of fruits is weight loss, occurring mainly by transpiration rate, which affects its marketability, being responsible for important economic losses. Since films used in modified atmosphere packaging have small water vapor pressure and then transpiration of tissues decreases enormously, leading to low weight losses. For example, in several fruits, such as loquat (Amoros *et al*., 2008), table grape (Martinez *et al*., 2003), nectarine (Retamales *et al.*, 2000), peach (Akbudak and Eris, 2004), and cherries (Kappel *et al*., 2002; Serrano *et al*., 2005).

2.2.2 Firmness

Nevertheless, the effect of modified atmosphere packaging on delaying softening could also be an ethylene mediated effect, since in apricots decreased film permeability led to increased CO_2 concentration and decreased ethylene production and softening (Pretel *et al.*, 1993). However, it has also been found that low O_2 concentration is more effective at inhibiting fruit softening than high CO_2 (Pretel *et al*., 1999).

Romero *et al*. (2009) found that tomato fruit firmness at harvest (6.99±0.19 Nmm^{-1}) decreased significantly during storage, although the loss of firmness was higher in control (stored at 8^{o}C) than in those stored at(8^{o}C either with activated carbon 1 per cent Pd (palladium) or the adsorbent catalyst device). Accordingly, grapes packaged in non-perforated PP film, berry and skin firmness were almost double than in control fruits after 14th days of cold storage (Martinez *et al.*, 2003b). This effect has been attributed to the reduction of cell wall degrading enzymes, such as polygalacturonase, by high CO_2 and low O_2 (Femenia *et al*., 1998).

Mutari and Debbie (2011) conducted an experiment on seventy two red ripe tomato fruits of the ‘Encore’ variety to access the effect of physical damage and storage temperature. Half fruits were dropped individually from a height of 1 m to stimulate rough handling while the remaining halves were not dropped. The fruits were then kept in sealed glass jars (six in each jar) and stored in two incubators set at 12 and 20^{o}C, respectively. They found that warmer fruits (20^{o}C) were less firm compared to colder ones (20^{o}C), while roughly handled fruits (damaged fruits) were less firm as compare to other one. Firmness was highest for tomato fruits treated with 0.1 MPa at 13^{o}C than tomato fruit under hypobaric treatment at varying pressure level (i.e., 0.1 0.5, 0.7 and 0.9 MPa) at ambient temperature (20^{o}C).

Tomato is a soft fruit that suffers from a rapid loss of firmness during storage, which contributes to its short postharvest life and susceptibility to fungal contamination (Hahn, 2014). Fruit firmness decreased continuously during storage, with a higher rate of decline in tomato fruit stored at higher temperatures. It has been reported that polygalacturonase (PG) and pectin methyl esterase (PME) activities are associated with tomato fruit softening. Therefore, it is possible that the maintenance of fruit firmness in tomato fruit by low temperatures was related to the inhibition of PME and PG activities and hence of cell wall degradation. The change in PG activity seems to correlate with the solubilization of pectin in tomato fruit (Calegario *et al*., 2001).

2.2.3 Respiration

Climacteric fruit, such as mango and papaya, apart from reduction of respiration rate, a delay on climacteric respiration peak has been reported (Singh and Rao, 2005; Yahia, 2006). in Chinese jujube. Respiration in control and chitosan coated fruit began to increase after 1 day storage at room temperature. In control and chitosan coated fruit, CO_2 production reaching maximum of 54.9 and 53.6 mg kg^{-1}h^{-1} on 4 and 7 day, respectively (Qiuping and Wenshui, 2007)

Tomato is characterized as a climacteric fruit on the basis of its ethylene production and respiratory activity, with the respiration peak preceding the ethylene burst by 1 day (Singh *et al*., 2013). Fruit respiration is a major factor contributing to postharvest quality losses (Guo *et al*., 2014). Mature green tomatoes, presented mean respiration rate around 90 mg kg^{-1}h^{-1} with no significant alteration during the postharvest period for fruit obtained at the local wholesale market, while for fruit harvested at a commercial grower, showed lower respiration rate 60 mg kg^{-1}h^{-1} w with similar behavior after harvest (Calegario *et al*., 2001)

It is possible that the high rates of respiration during ber fruit ripening are responsible for the short storage life of the fruit under room temperature conditions. Respiration rate increased from green mature to fully ripe stage, then again declined in over-ripe fruits (Singh *et al*., 2013).

The rate of respiration of mature tomato under closed system at 5, 10, 15, 20, 25 and 35^{o}C was higher initially and gradually declined with advancement of storage then it became almost constant. The respiration rate for CO_2 evolution were observed to be 14.35, 15.04, 19.95, 21.7 and 20.3 ml kg^{-1}h^{-1} at 10, 15, 20, 25 and 35^{o}C, respectively. The respiration rate based on carbon dioxide evolution and oxygen consumption in closed condition decreased by about 46 per cent and 73 per cent, respectively, relative to initial respiration values at normal air atmosphere. The result suggested that the respiration rate of tomato increased with temperature and decreased with storage time (Singh *et al*., 2013). The total respiration rate increased rapidly for control, reached maximum at 9th day, however, the peak of total respiration rate and cyanide resistant respiration in fruit treated with ClO_2 was reduced about 29 per cent 24 per cent, respectively (Guo *et al.*, 2014). Muttari and Debbie (2011) found that storage temperature had statistically significant effects on respiration with higher respiration rate at 20^{o}C as compare to 12^{o}C temperature.

2.2.4 Ethylene Production

Red colour development (associated with ripening) in tomatoes is triggered by ethylene activity in the presence of oxygen leading to the synthesis of the pigment lycopene which is responsible for the red colour. Low oxygen levels coupled with high carbon dioxide concentration reduce ethylene activity. This may explain why ripening was delayed in the polyethylene bag packed fruits (Edusei and Cornelius 2015).

Ripening and ethylene production is initiated in mature green tomatoes in the locular gel coincident with disintegration of that tissue, the cell wall of which are completely degraded. From there, ripening proceeds through the placenta to the core, with the first visible sign of ripening being the appearance of red (or yellow or orange) pigmentation at the distal or blossom end of the fruit, at which point the fruit is said to be at ‘breaker’ stage. Ripening then progresses toward the proximal end of the fruit unitl the entire fruit attains its final, fully ripe colour. Ripening of mature green tomatoes accelerated by exposure to ethylene at concentration more than 0.05 ul 1^{-1} (Wills *et al*., 2001), however, at the breaker and later stages of ripening, tomato fruit are not affected by ethylene exposure as enough ethylene is produced endogenously to saturate the ripening processes.

2.2.5 Ripening index (RI)

Among three storage treatments of CAS, Cold and MAP, highest variation of ripening index were found in the cold storage treatment. Result showed that ripening index in cold storage first reached maximum value of 13.35, and then there was a decrease followed by an increasing trend (Majidi *et al*., 2011). Genanew (2013) reported that RI in tomato fruits treated with different concentration of $CaC1_2$ with and without modified atmosphere packaging, result showed that ripening index initially starts from 8.89 and increases as fruit matures and reached to 26 at the 2nd week due to complete loss of titratable acidity. He also reported that fruits present in modified atmosphere had reduced RI in the 2nd week than those exposed to ambient environment.

Luengwilai *et al*. (2012) observed a linear decrease in ripening score in mature green fruits of tomato after treansferred at 20^{o}C for fourteen days from storage at 2.5^{0}C for 0 to 3 weeks. The ripening score decreased 15 per cent after one week of chilling, but it was not significantly different from that of the non chilled (control) fruits. Tomatoes chilled (stored at 2.5^{o}C) for 2-3 week produced a significantly decrease of 35 per cent in the ripening score.

Santos and Realpe (2013) reported RI value 10.94, 9.08, 7.95 for cultivar Milano, LL-Milano, Chonto, respectively. RI was found to be more strongly influenced by storage temperature since treatment at 0.1 MPa at 13^{o}C resulted in significantly less increase in RI compared to all other hypobaric treatment (0.1, 0.3, 0.5, 0.7 and 0.9 MPa) at 20^{o}C. There was a significant increase in RI on the 5th day after hypobaric treatment. As ripening progressed for another 5 days (10 days after hypobaric treatment), ripening index was declined slightly but not significantly, except those of tomatoes subjected to 0.7 and 0.9 MPa (Liplap *et al*., 2013).

2.2.6 Total soluble solids (TSS)

Pila *et al*. (2010). Suggested that fruit treated with GA_3, $CaCl_2$, SA treatments retained lower TSS value than control after 10 days of storage indicating delay in fruit softening process as well as starch degradation.

Total soluble solid of mature green tomato stored at 13^{o}C initially increases up to 20 days, after that starts decline (Majidi *et al*., 2011). TSS of tomato fruit harvested at breaker stage increased with storage period of 12 days at ambient temperature for cultivar H-86, DVRT-1, Avinash-2 and BSS-422 (Rai *et al*., 2012).

Chucha cultivar presented the highest TSS increase at all tested temperatures, ranging from 2.9 per cent when stored at 6^oC to 13.2 per cent at 25^oC followed by Cereja and Rama cultivar, respectively. TSS of tomato fruit reduced in the first week (5.6 to 3.5^0B) and proceeds almost constantly in all $CaCl_2$ treatments during storage period of four week (Genanew, 2013 ; Mujtaba and Masud, 2014).

2.2.7 Acidity

Toor and Savage (2006) suggested that titratable acidity was significantly lower (0.77%) at 7^oC as compared to 15^oC and at 25^oC (0.97% and 0.06% respectively) after 10 days of storage indicating the inhibition of production of organic acid and higher keeping quality.

Nasrin *et al.* (2008) observed that acidity decreased slowly in tomato fruits treated with chlorine, packet in perforated polyethylene bag (0.25%) and stored at 4^oC. TA decreased gradually in tomato fruit stored at 13^oC for 40 days from 0.47 to 0.37 per cent with increasing days of storage.

Santos and Realpe (2013), suggested that cultivar LL-Milano, Milano and Chonto have TA 0.37 per cent, 0.41 per cent and 0.54 per cent, respectively for ripe fruits stored at 4^oC.

2.2.8 Ascorbic Acid

However, an important primary negative response to low O_2 is the induction of fermentation, leading to accumulation of acetaldehyde, ethanol, and lactate. Generally, the lower limit of O_2 content in the atmosphere is considered to be the O_2 level at which the fermentation is induced. In climacteric fruit, such as mango and papaya, apart from reduction of respiration rate, a delay on climacteric respiration peak has been reported (Singh and Rao, 2005; Yahia, 2006)

Ascorbic acid content during storage was continuously increasing with slight fall during the 20^{th} day of storage (Mujtaba and Masud, 2014). A slight accumulatin of ascorbic acid was observed during storage of 10 days at all three temperatures 7^oC,

15^oC and 25^oC studied wait more accumulation at higher temperature (Toor and Savage, 2006).

Rai *et al.* (2012) revealed that the ascorbic acid content of breaker stage tomato decreased gradually during storage of 12 days at ambient temperature for all four cultivar H-86, DVRT-1, Avinash-2 and BSS-422.

2.2.9 Sugars

Ling *et al.* (2008) reported that the soluble sugar mainly consisted of sucrose, glucose and fructose. The sucrose contents in fruits of four cultivars increased quickly from mid-late stage of inflation to ripening, and the rate of sucrose accumulation in 'Gaolangyihao' was faster than that of the other three cultivars. The rule of fructose and glucose accumulation in 'Gaolangyihao' was similar to that of 'Xinshiji', and fructose content was almost equal to glucose content, the change in those contents were not obvious during the fruit development. The content of fructose was significantly higher than that of the glucose in 'Mizao' and 'Miandianchangguo' fruit (Ling *et al*., 2008). Somboonkaew and Terry (2010) studied biochemical profiles of imported litchi fruit under modified atmosphere packaging. Non-acid and SO_2 free fruit cv. 'Mauritius' were packed using four different packaging films *viz*. microperforatedpolypropelene (PP), PropaFresh^{TM} PFAM (PF), NatureFlex^{TM} NVS (NVS), Cellophane^{TM} WS (WS) and unwrapped and stored at 13ºC for 9 days. The PF treatment better maintained sugars, organic acids, in aril and pericarp tissue and individual anthocyanins in pericarp. Total sugars increased gradually up to certain period of growth and then decreased rapidly (Bal and Singh, 1978)

2.2.10 Lycopene

Javanmardi and Kubota (2006) suggested that lycopene content of tomato fruit stored at room temperature for 7 days was significantly higher (42-68 mg/kg) than low temperature stored tomatoes (40-37 mg/kg). It was also found significantly higher during first 7 days at 12^0C than the next 7 days at 5^0C. The same result was reported by Ajlouni *et al.* (2001).

Pila *et al.*, (2010) concluded that more accumulation of carotenoids and lycopene in the fruits of control were found to be statistically significant, while the chemically treated fruits ($GA_{3<}$ $Cacl_2$ and SA) showed lesser and slow accumulation of lycopene during storage.

Pek and Helyes (2010) revealed negative effect of high storage temperature on lycopene content of tomato fruit wherein storge of tomato fruit at 30^0C result in lowest lycopene content (2.1 mg/100 g) than lycopene (3.9 mg/100 g) in tomato stored at 15^0C temperature.

Mujtaba and Masud (2014) concluded that $CaCl_2$ treated fruit show less lycopene content than control during storage and suggested that calcium choloride as ethylene absorbent.

2.2.11 Colour

Accordingly, all individual color parameters (L^*, a^*, and b^*) significantly increased in unwrapped control broccoli during storage, which was related to both the yellowing process of broccoli inflorescences and the decrease in chlorophyll (a+b) concentration. However, broccoli under modified atmosphere packaging condition retained the green color characteristic of freshly harvested broccoli after 21 day of storages and chlorophyll degradation and browning mediated by the inhibition of pheophorbi deoxigenase and PPO, responsible for chlorophyll loss and browning, respectively (Beaudry, 2000).

In papaya, modified atmosphere packaging helped in maintenance of antioxidant potential of fruit by retaining acceptable levels of antioxidants, such as ascorbic acid and lycopene (Singh and Rao, 2005).

Pek and Helyes (2010) observed more rapid development of red colour in fruit stored at 30°C than those fruits stored at 15°C or developed on the vine. The hue value of fruit stored at 30°C was significantly higher (less red) than of those ripened at 15°C or on the vine.

Genanew (2013) resulted that colour of tomato fruit changes during storage and became deep red in 4 weeks. Values of a were found less at lower temperature (12°C) than at higher temperature (20°C) (Mutari and Debbie, 2011and Robert *et al.,* 2002).

Colour development of tomato was inhibited not only by the lower temperature (13°C) but also by hypobaric pressure (Liplap *et al.,* 2013 and Goyette *et al.*, 2012). Tomato colour index increased over storage in both skin apipulp at 8°C (Romero *et al.,* 2009).

Bhatia *et al.* (2014) found continues increase M colour values of tomato during storage of 14 days. Color evaluation associated with the postharvest ripening process is generally delayed in fruit stored under modified atmosphere packaging condition, as compared to those stored in open air, as has been shown in mango (Pesis *et al*., 2002) table grape (Martinez-Romero *et al*., 2003) and loquat (Amoros *et al*., 2008).

2.3 Effect of packaging material on postharvest physiology and quality of tomato fruit

The research work undertaken in the past in various fruits on different aspects *viz*., physico-chemical characteristics of fruits, shelf life, postharvest physiology, quality and sensory properties influenced by different packaging and storage temperature are briefly reviewed. Packaging is an essential component of the food system and plays a critical role in containing, protecting and preservation food and other agro-industrial raw materials from field to the end user. Packaging is often used as a tool to extend shelf life by preventing or reducing water loss, especially in fresh produce.

Unpacked foods are often exposed to a range of microorganisms which have the potential to reduce shelf-life (Paine and Paine, 1992). Miller and Krochta (1997) showed that polyethylene bags reduced water loss and extended storability of various fruit and vegetables.

Noor *et al*. (2002) conducted an experiment on the effect of different packing materials on the storage life of tomatoes (cv. Peshawer Local) and found that the maximum weight loss (224.1 g) occurred for unpacked fruits while the minimum of 77.5 g was recorded for tomatoes packed in black polyethylene bags at 10°C for 15 days. The best colour retention was noted in black polyethylene bags; while, it was the poorest in the control and perforated bags. Skin firmness was best in the black polyethylene bags and lowest in the control. Overall, the best results were given by the black polyethylene bags.

Park *et al*. (2004) packaged tomato fruits in low density polyethylene or ceramic film and stored for 28 days at 4 or 10°C. Fresh weight was maintained better at 4°C and 40 cm film treatments. The contents of CO_2 and ethylene in film packages were the lowest in the 20 cm CE film at 4°C treatment. These contents were 1.5-times higher at 10°C than those recorded at 4°C. The lower the CO_2 and ethylene concentration better was the quality, especially firmness effectively maintained in MA storage at 4°C. The best MA treatment for storage of tomato fruits was the 20 cm CE film at 4°C.

Syamal (2006) concluded that the highest weight loss (30-40%) was found in perforated polythene bag due to the higher rate of transpiration, which was found lower in sealed polythene bags. Further, weight loss of tomatoes depends upon the transpiration and respiration rate of the tomato fruit during its storage, which were found lower under sealed condition.

Shahnawaz *et al.* (2012) reported that polythene packaging create modified gas atmospheres around the product which slows down the respiratory activity of tomato, extended the length of ripening time and significantly decreased weight loss in wrapped tomato as compared to control tomato fruit.

2.4 Effect of storage temperature on postharvest physiology and quality of tomato fruit

Chilling injury symptoms and increased decay did not appear for longer than two weeks if held below 10°C while these symptoms appear within 6-8 days if stored at 5°C. Expression of symptoms is usually delayed if fruits are exposed to room temperature for 2 days or longer. Tomato fruit stored for 7 days at 5°C and ripened at 20°C had acidic taste and low flavor (Kader *et al*., 1978).

Fruit in advance ripening stages can tolerate low temperature and are less sensitive to chilling but there is a risk to develop chilling injury in mature green tomatoes, if held for 2 weeks or longer at below 13^{o}C temperature (Hardenburg, *et al.* 1986).

Tomatoes stored at 0 or 5°C. symptoms of CI became evident after approximately 4-8 days of storage and progressed to attain a maximum acceptable level after 14 days (Prolux *et al*., 2001).

Suslow and Cantwell (2002) concluded that low temperature storage is widely used as post harvest treatment for delaying senescence, ripening process and maintaining their post harvest quality but tomato is chilling sensitive below 10ºC, if held for longer than two weeks or at 5ºC for longer than 6-8 days.

Salveit (2003) tomato fruits can be are stored at 10-15°C to extend shelf life and for every 10°C increase in storage temperature above optimum, the rate of fruit deterioration will be increased 2-3 fold.

Park *et al.* (2004) conducted an experiment with tomatoes at 2 maturity stages viz breaker and pink were coated with corn-zein film, control (non-coated) and coated tomatoes were stored at 21°C. They found that corn-zein film delayed color change and loss of firmness and weight reduced in storage. They also reported that coating fruits with corn-zein film extended the shelf life by 6 days.

Castro *et al*. (2005) reported that tomato can be stored at ambient temperature for a period of up to 7 days and up to 18 days at a temperature of 10-15°C and 85-95 relative humidity. Low temperature conserve firmness, acidity and low decay percent. At these temperatures chilling injury symptoms were also noticed.

Kaynes and Surmeli (2005) recorded that tomato fruits exhibited a shelf life up-to 40 days at 12°C when fruits stored at green mature, breaker and pink fruits stages; similarly, it could be stored for 25-30 days at 8°C. They also stated that tomatoes at the light red and red stages can be held for 10-15 days at 8°C and for 10 at 12°C.

In papaya, modified atmosphere packaging helped in maintenance of antioxidant potential of fruit by retaining acceptable levels of antioxidants, such as ascorbic acid and lycopene (Singh and Rao, 2005).

Kumar *et al.* (2008) stated that at room temperature the tomato fruits could be stored up-to 12 days only with less than 10% weight loss compared to 20 days at 10°C and 28 days at 5°C and the respiration rate was higher in ethaphon treated fruits than those ripened on the plants.

Wainwright (2008) studied the shelf life of a fresh market tomato cultivar (Money Maker) and a processing tomato cultivar (Cal-J) at 4.5°C, room temperature (18-25°C) and 30°C. Weight loss was significantly higher at increased temperatures and there was an interaction between cultivar and temperature at room temperature and 30°C. Loss of fruit firmness was greatest at the 2 higher temperatures but there were no significant differences between the cultivars. The difference in shelf life was significant between temperature levels and cultivars. Money Maker had a longer shelf life than Cal-J under all conditions, but storage temperature rather than cultivar was the major factor determining shelf life.

Znidarcic *et al*. (2010) found that middle red ripe stage tomato cv. Belle fruits stored at 10ºC lost their weight rapidly and accelerated ripening process as compared to fruit stored at 5ºC. They also observed high Vitamin C, TSS, lycopene content, low decay percent and more shelf life of the fruit under lower storage temperature.

3. MATERIALS AND METHODS

This chapter describes the experimental set-up, materials methods used and techniques followed in the present investigation entitled **"Response of Polyethylene Packaging and Storage Temperature on Postharvest Physiology and Quality of Tomato"** was conducted in the fruit and vegetable processing unit, Department of Horticulture, Rajasthan College of Agriculture, MPUAT, Udaipur, during the month of February, 2017. The chapter also includes the description of raw materials, physiological, biochemical and quality evaluation methods.

3.1 Climate and weather condition

Udaipur falls under semi arid climate of agro-climatic zone IV- A (Semi Arid Southern Zone). It is situated at 24ºN latitude and 75ºE longitude at an elevation of 559.65 m above mean sea level. The daily weather report of maximum and minimum temperature and relative humidity of laboratory for the experimental period is given in Table 3.1.

3.2 Details of the experimental materials and methodology

3.2.1 Selection of fruit

The fruits were harvested at colour turning stage (initial pink colour development stage) by hand from Horticulture farm, RCA, Udaipur and brought to the fruit and vegetable processing unit within an hour.

3.2.2 Sample preparation for treatment

The homogeneous fruits were selected for uniformity, fully matured but unripe fruit of tomato (*Lycopersicum esculentum* L.) were used for all the experiment in this study. Defective, immature, over mature, spotted and blemished fruits were discarded. The selected fruits were thoroughly washed with tap water to remove dirt and dust particles adhering to the surface of fruits and then again washed with chlorinated water were allowed to shade dry before giving treatment.

3.2.3 Plastic film and Packaging

The fruit were packed and sealed by electric sealing machine in 20, 40, 60, and 80 µ thicknesses low density plastic bags and fruit wrapped in news paper served as control. Approximately of 250 g fruits used per treatment. The gas permeability was measured using OTR (OTR model OPT-500, PBI Dansensor, Denmark).

3.2.4 Distilled water

To prepare the reagents for biochemical analysis during investigation the HPLC grade ultrapure water with zero TDS and zero minerals (Ultrapure water purification system, Sartorius, Germany) was used.

3.2.5 Chemicals

Analytical grade chemicals (Sigma Aldrich, USA; SRL, India; Thomas Backer, India) were used to prepare reagents for biochemical analyses.

3.2.6 Storage conditions

The packages were sealed by electric sealing machine and immediately stored at 6 ºC, 12 ºC and ambient or room temperature for 15 days, at 80-90% RH. There were three replicates per treatment with 6 units per treatment per replication and finally sealed bag stored in the different storage condition. Therefore, total 21 treatment combinations were used in this experiment. The details of packaging materials, storage temperatures, and their combinations with notations used are given in Tables 3.3 and 3.4

Table 3.1 Temperature and relative humidity recorded in laboratory during experimentation period

Date	Temperature (%)			Relative humidity (%)	
	Max.	Min.		Max.	Min.
8.2.2017	30.5	10.1		77	28
9.2.2017	30.3	10.2		82	25
10.2.2017	31.1	13.2		69	25
11.2.2017	32.4	13.3		75	29
12.2.2017	29.8	10.0		77	30
13.2.2017	33.3	12.9		84	28
14.2.2017	32.0	13.3		81	22

Date	Temperature (%)			Relative humidity (%)	
	Max.	Min.		Max.	Min.
15.2.2017	31.5	14.5		76	31
16.2.2017	31.8	11.8		78	29
17.2.2017	30.9	12.7		74	23
18.2.2017	30.7	14.8		71	28
19.2.2017	32.0	13.2		79	24
20.2.2017	33.7	13.1		78	26
21.2.2017	34.1	14.2		76	25
23.2.2017	30.9	13.8		75	21
24.2.2017	31.0	13.1		72	23
25.2.2017	30.3	13.9		78	25
26.2.2017	30.4	12.7		71	24
27.2.2017	31.1	12.9		72	26
28.2.2017	31.0	14.2		71	27
1.3.2017	28.3	13.9		72	32
2.3.2017	31.1	13.9		68	25
3.3.2017	32.1	14.1		69	27
4.3.2017	32.1	14.2		71	34
5.3.2017	33.4	14.0		73	28
6.3.2017	34.1	15.1		73	28
7.3.2017	33.3	14.8		69	23
8.3.2017	34.0	14.7		67	30
9.3.2017	32.1	15.1		62	37
10.3.2017	32.2	15.2		72	32
11.3.2017	31.8	15.7		71	21
12.3.2017	32.1	14.7		59	28
13.3.2017	33.2	14.3		67	29
14.3.2017	34.0	14.5		71	24
15.2.2017	33.7	14.9		68	31

Table 3.2 Equipments and their models used for the experiment

S. No.	Name of equipment	Model
1	Modified Atmosphere Packaging Machine	VAC STAR S 220 MP
2	Gas Mixture	MAP Mix 9001, PBI Dansensor, Ringsted, Denmark.
3	Electronic Moisture Analyzer	MA 100, Sartorius, Germany,
4	Texture Analyzer	TA. XT Plus, Stable Micro Systems Limited, Godalming, Surrey, UK.
5	Head Space Gas Analyzer	6600, Systech Instruments, Oxfordshire, UK.
6	Ethylene Analyzer	Ethan, Bioconservacion, Spain
7	“Zeiss” Hand Refractometer	
8	pH meter	827 pH Lab, Metrohm, Swiss Mode, Switzerland.
9	Hunter Color Flex	Hunter Associates Laboratory Inc., Reston, VA, USA)
10	DA Meter	S-2000, Ocean Optict, Dunedin, USA
11	Spectrophotometer	Double beam SL 210 UV Visible Spectrophotometer, Ellico, Hyderabad, India
12	Ultrapure water purification system	Ultrapure water purification system, Sartorius, Germany
13	Cold storage	

Other details of experiment

(i)	Name of fruit	:	Tomato (*Lycopersicon esculentum* L.)
(ii)	Name of cultivar	:	Dev
(iii)	Statistical design of experiment	:	Factorial CRD
(iv)	Total No. of treatment combinations	:	15
(v)	Number of replications	:	3
(vi)	Quantity of fruit to be used	:	Approximate 250 g per treatment
(vii)	Units	:	6
(viii)	Observations will be recorded at	:	5 days interval

Table 3.3 Details of the treatments used

(A)	**Packaging material**	**Notation**
(i)	Control (without packaging)	P_1
(ii)	Low Density Polyethylene Bag (LDPE) (20µ thickness)	P_2
(iii)	Low Density Polyethylene Bag (LDPE) (40µ thickness)	P_3
(iv)	Low Density Polyethylene Bag (LDPE) (60µ thickness)	P_4
(v)	Low Density Polyethylene Bag (LDPE) (80µ thickness)	P_5
(B)	**Storage temperature**	**Notation**
(i)	Ambient storage	T_1
(ii)	12^{o}C	T_2
(iii)	6^{o}C	T_3

Table 3.4 Details of various treatment combinations

(C)	**Treatment Combinations**	**Notation**
(i)	Control (without packaging) + Ambient storage temperature	P_1T_1
(ii)	Control (without packaging) + 12^{0}C storage temperature	P_1T_2
(iii)	Control (without packaging) + 6^{0}C storage temperature	P_1T_3
(iv)	LDPE Bag (20µ thickness) + Ambient storage temperature	P_2T_1
(v)	LDPE Bag (20µ thickness)+ 12^{0}C storage temperature	P_2T_2
(vi)	LDPE Bag (20µ thickness)+ 6^{0}C storage temperature	P_2T_3
(vii)	LDPE Bag (40µ thickness)+ Ambient storage temperature	P_3T_1
(viii)	LDPE Bag (40µ thickness)+ 12^{0}C storage temperature	P_3T_2
(ix)	LDPE Bag (40µ thickness)+ 6^{0}C storage temperature	P_3T_3
(x)	LDPE Bag (60µ thickness)+ Ambient storage temperature	P_4T_1
(xi)	LDPE Bag (60µ thickness)+ 12^{0}C storage temperature	P_4T_2
(xii)	LDPE Bag (60µ thickness)+ 6^{0}C storage temperature	P_4T_3
(xiii)	LDPE Bag (80µ thickness)+ Ambient storage temperature	P_5T_1
(xiv)	LDPE Bag (80µ thickness)+ 12^{0}C storage temperature	P_5T_2
(xv)	LDPE Bag (80µ thickness)+ 6^{0}C storage temperature	P_5T_3

3.5 Methodology used for recording observations

Before giving treatments initial physiological and biochemical observations were recorded from the randomly selected fruits. The subsequent observations on physiological, biochemical and sensory changes were recorded at 5 days interval. The following observations were recorded during the course of investigation.

A. Physiological Characteristics			
1.	Physiological loss of weight	Percent	By measuring initial and final weight
2.	Firmness	Firmness	Texture Analyzer
3.	Respiration rate	ml Co2 kg 1 h^{-1}	Head Space Gas Analyzer
4.	Ethylene production	µl C_2H_4 kg $^{-1}$ h^{-1}	Ethylene Analyzer
5.	Ripening index	Per cent	Va´squez-Caicedo *et al*. (2005)
B. Quality Characteristics			
6.	TSS	$^{\circ}$Brix	Digital Refractometer, AOAC (2007)
7.	Acidity	Per cent	Titration Method, AOAC (2007)
8.	Ascorbic acid	mg $100g^{-1}$	Metaphosphoric Acid, AOAC (2007)
9.	Total sugar	Percent	Anthrone Reagent Method
10.	Reducing sugar	Percent	Dinitrosalicylic Acid Method (Miller, 1959)
11.	Lycopene	mg $100g^{-1}$	Sadasivam and Manickam (1991)
C. Sensory Evaluation and Colour Evaluation			
12.	Decay	Per cent	Visual Observation
13.	Hunter color values	L*, a* & b*	Hunter Color Flex
14.	Overall organoleptic score	Out of 10 marks	10- Hedonic Scale
15.	Chilling injury index	Out of 5 marks	Five point hedonic scale

3.4.1 Physiological characteristics

3.4.1.1 Physiological loss in weight (%)

Cumulative physiological loss in fruit occurred due to transpiration and other physiological processes. To determine the CPLW, 100 g fruits in each treatment were marked. The marked fruits were weighed on subsequent dates. The same marked fruits were weighed on 3 days interval during experimental period. The CPLW or per cent loss in weight for each treatment during storage was calculated by using following formula:

$$\text{PLW (\%)} = \frac{\text{Initial weight (g)} - \text{final weight (g)}}{\text{Initial weight (g)}} \times 100$$

3.4.1.2 Firmness (Newton)

TA.XT Plus/TA.HD Plus Textural Analyzer used for measuring textural properties of is shown in Plate 3.2. The texture analyzer (TA) was a microprocessor controlled analysis system, which could be interfaced to a wide range of peripherals, including PC-type computers. The texture analyzer measured force, distance and time in a most basic test, thus providing three dimensional product analyses. Forces could be measured against set distances and distances may be measured to achieve set forces. The probe carrier contained a very sensitive load cell. The TA.HD plus load cell had electronic overload protection. The TA-XT plus load cell had mechanical overload. The analyzer was linked to a computer that recorded the data via a software program Stable Micro System Exponents software (Stable Micro Systems).

Penetration Test by Using Cylindrical Probe

The penetration test is defined as one in which the depth of penetration (or the time required to reach a certain depth) was measured under a constant load. In a penetration test, the cylinder probe was made to penetrate into the test sample and the force necessary to achieve a certain penetration depth or the depth of penetration in a specified time, under defined conditions, was measured and used as an index of firmness. In penetration test, firmness was represented by hardness and factorability. The area under the curve was taken as an indication of the hardness (kg) and the linear distance as an indication of factorability of the product during textural analysis (StableMicro systems).

3.4.1.3 Respiration rate (µl CO_2 kg^{-1} h^{-1})

The indirect respiration rate of fruit was determined in a static system. The samples (approximately 50 g) were placed in a sealed 100 ml glass jars with silicon septum. The initial CO_2 concentration was measured using Head Space Gas Analyzer (model 6600, Systech Instruments, Oxfordshire, UK) by inserting the equipment needle through a silicon septum attached to the glass jar. After 1 h time CO_2 concentration again measured. The difference in CO_2 concentration then converted to kg^{-1} fruit h^{-1} by considering volume of glass jar. The results were expressed in ml CO_2 kg^{-1} h^{-1}.

3.4.1.4 Ethylene evolution rate (µl C_2H_4 kg^{-1} h^{-1})

To measure the ethylene production rate, 100 g fruit of six replicates were enclosed separately in airtight jars and determined the ethylene evaluation rate by using pump module Gas Alert Micro 5 PLD PV (Voilen Canada). Ethylene synthesis was recorded in µl ethylene kg^{-1} h^{-1}.

3.4.1.5. Ripening index

Postharvest ripeness of the ber fruits was quantitatively described by a ripening index (RPI_{KS}) calculated by below given formula, where the dimensionless fruit firmness ($SF_{KS} = |SF_{KS,i}|$) refers to the absolute value of the specific maximum load at the ripening time RT_i (in days) and TSS/TA specifies the sugar/acid ratio of the corresponding ber mesocarp sample that was calculated from TSS and TA (Vasquez-Caicedo, 2005).

$$RPI_{KS} = \ln (100 X\ SF_{KS} X\ TSS/TA)$$

3.4.2. Biochemical observation

3.4.2.1 Total soluble solid (^{0}B)

The TSS content of fruit pulp was directly measured by the “Zeiss” Hand Refractometer (0-30) and value obtained was corrected at 20ºC (AOAC, 2007).

3.4.2.2 Acidity (%)

The acidity of fruit pulp was determined by diluting the known volume of pulp with distilled water and titrating the same against standard N/10 sodium hydroxide solution, using phenolphthalein as an indicator. The appearance of light pink color was taken as the end point. The acidity was expressed in terms of per cent acidity.

$$\text{Acidity (\%)} = \frac{0.0064 \times \text{Volume of NaOH use} \times 100}{\text{Volume of sample taken}}$$

3.4.2.3 Ascorbic acid (Vitamin C) analysis

Ascorbic acid is a sugar acid with antioxidant properties. Its appearance is white to light-yellow crystals or powder, and it is water-soluble. One form of ascorbic acid is commonly known as vitamin C. The concentration of a solution of ascorbic acid can be determined in many ways, the most common ways involving titration with an oxidizing agent (Ranganna, 1986).

Take 5 ml of standard ascorbic acid solution and add 5 ml of 3per cent HPO_3. Fill a micro burette with dye (dissolve 50 mg of 2, 6-dichlorophenol-indophenol in 150 ml of hot distilled water containing 42 mg $NaHCO_3$). Titrate with the dye solution to a pink colour which should persist for 15 sec. determine the dye factor, i.e. mg of ascorbic acid per mol of the dye, using the formula:

$$\text{Dye Factor} = 0.5/\text{ Titrate}$$

Take an aliquot (5ml) of the HPO_3 extract of the sample and titrate with the standard dye to pink end-point which should persist for at least 15 sec. Titrate rapidly and make a preliminary determination of the titre. In the next determination, add most of the dye required and then titrate accurately. The aliquot of sample taken should be such that the titre should not exceed 3 to 5 ml. The ascorbic acid content of the sample can be calculated from the following formula:

$$\text{Mg of ascorbic acid per 100 g} = \frac{\text{Titrate X Dye factor X Volumemade up}}{\text{Aliquot of extract X Wt of sample}}$$

3.4.2.4 Total sugar (%)

Total sugars content was determined by using anthrone reagents method (Dubois *et al*., 1951). To 1 ml of diluted sample (100 times), 4 ml of anthrone reagent was added, then heated for 10 to 15 minutes on a water bath, cooled to room temperature and absorbance was measured at 630 nm on spectrophotometer (Systronics UV-Vis spectrophotometer 108). The amount of sugars present in the sample was plotted against standard curve prepared from glucose. The value was expressed in terms of percentage.

3.4.2.5 Reducing sugar (%)

Reducing sugar content was measured as suggested by Miller (1959) using dinitrosalicylic acid. Sugars were extracted with hot 80 per cent ethanol in 100 mg sample. Supernatant was collected and evaporated by keeping on a water bath at 80°C and 10 ml water was added. After dissolving of sugars, 3 ml extract was pipette out and 3 ml DNS reagent was added in 3 ml extract. 1 ml of 40 per cent Rochelle salt solution was added in hot DNS- extract mixture. After cooling, absorbance was measured on spectrophotometer (Double beam SL 210 UV Visible Spectrophotometer, Ellico, Hyderabad, India) at 510 nm. The value was plotted against a standard curve prepared from glucose. The figures were expressed on percentage basis.

3.4.2.6 Lycopene (mg 100^{-1})

Five gram of tomato pulp was extracted repeatedly with acetone using pestle-mortar until the residue was colorless. The acetone extract were transferred into separating funnel containing 20 ml of petroleum ether and mixed gently. Subsequently, 20 ml of 5 percent sodium sulphate was added and shaked gently. Petroleum ether might be added more as it was reduced during this process because of its evaporation. After well shaked, the separating funnel was kept on funnel stand. After some time, two layers were formed in separating funnel. Most of the colour was noticed in the upper petroleum ether layer. Lower aqueous phase was re-extracted with additional 20 ml petroleum ether until the aqueous phase was colourless. Upper petroleum ether extract layer were pooled into brown bottle containing 10 gram anhydrous sodium sulphate. After 30 minutes, petroleum ether extract was decanted into 100 ml volumetric flask through a funnel containing cotton wool. Volume was made 100 ml and absorbance was read on spectrophotometer (double beam SL 210 UV Visible spectrophotometer, Ellico. Hyderabad, India) at 503 nm using petroleum ether as blank. The lycopene content (mg/100g) was calculated by using following formula (Sadasivam and Manickam, 1992).

$$\text{Lycopene content (mg/100g)} = \frac{31.206 \times \text{Absorbance}}{\text{Wt. of sample taken}}$$

Absorbance for one unit = 3.120 µg lycopene/ml

3.4.3. Colour and Sensory evaluation

3.4.3.1 Decay (%)

Decay is the process of rotting or decomposition through the action of bacteria and fungi. The decay or rotting of the stored tomato fruit were determined by their visual observations. Decay percentage of tomato fruits was calculated as the number of decayed fruits divided by received number of fruits multiplied with 100 (Pila *et al.*, 2010).

$$\text{Decay (\%)} = \frac{\text{No. of decayed fruits X 100}}{\text{Total No. of fruits in initial}}$$

3.4.3.2 Colour coordinates (L*, a*, b* values)

Colour is important to consumer as a mean of identification, as a method of judging quality and for its basic esthetic value and food is no exemption. The overall objective of colour to the food is to make it appealing and recognizable. The colorimeter used in the present investigation is presented in Plate 3.3. Colour of the Jamun was measured using a Hunter Color Flex (HunterLab Color Flex, Hunter Associates Laboratory Inc., Reston, VA, USA) according to Nielsen (2010). The Hue (H), Chroma (C), which represents color intensity and saturation were calculated according to the following equations

1. $Hue = \tan^{-1}\frac{b}{a}$

2. $Chroma = (a^2 + b^2)^{1/2}$

3.4.3.3 Overall organoleptic score (out of 10 marks)

The organoleptic-evaluation of jamun fruit was judged by the visual method and on the basis of palatability, scored from 1 to 10 on Hedonic Rating Test Scale. For this purpose, a panel of five judges, who examined the skin color, pulp color, texture, sweetness and overall acceptance of ber fruits. The organoleptic-evaluation of ber fruit was examined up to 35 days at seven days interval of storage period (Ranganna, 1978).

Category	**Marks**
Extremely acceptable	10
Very much acceptable	9
Moderately acceptable	7
Slightly acceptable	6
Neither acceptable nor unacceptable	5
Slightly unacceptable	4
Moderately unacceptable	3
Very much unacceptable	2
Extremely unacceptable	1

3.4.3.4 Chilling injury (out of 10 marks)

CI index was determined with rating of fruit skin (skin affected by pitting and skin discoloration symptoms) by using a five-point hedonic scale based on the surface area of fruit affected (Gonzalez-aguilar *et al.*, 2003). The hedonic scale was used; 1, mark for <20% of affected area in the fruit; 2 mark for 20- 40% of affected area in the fruit; 3 mark for 40-60% of affected area in the fruit and 5 mark for >80% of affected area in the fruit. The average CI index was determined as indicated in the following formula:

CI index = Sum (Hedonic scale × number of fruit with corresponding scale number divided by total number of fruit.).

3.5 Statistical analysis

The experimental design was factorial complete randomized design. Data obtained on various characters from two seasons were analyzed separately. According to the analysis of variance techniques as suggested by Gomez and Gomez (1984). The analysis of variance for different parameters is presented in Appendices. The critical difference (CD) was calculated to access the significance or non significance of difference between treatment means. Wherever it was found significant through ‘F’ test at 5 per cent level of significance, marked as star in ANOVA Tables.

4. EXPERIMENTAL RESULTS

The results of the experiment entitled **"Response of Polyethylene Packaging and Storage Temperature on Postharvest Physiology and Quality of Tomato cv. Dev"** conducted in Post Harvest Technology Laboratory, Department of Horticulture, Rajasthan College of Agriculture, Udaipur during 2017 has been presented in this chapter. The data pertaining to the different treatments on various physiological, biochemical characteristics and sensory evaluation were analyzed using standard statistical methods in order to test their significance. The data recorded for important characters have also been presented graphically for elucidation of the important trends. The analyses of variance for different components have been presented in appendices at the end. The results obtained with regard to various physical and physiological characteristics are described below:

4.1 Physical and physiological characteristics

Data pertaining to the effect of different packaging material, storage temperatures and their combinations on physical and physiological characteristics like cumulative physiological loss in weight (%), firmness (Newton), respiration rate (ml CO_2 kg^{-1} h^{-1}), ethylene evolution rate (µl C_2H_4 kg^{-1} h^{-1}) and ripening index (%) during storage are presented in Tables 4.1 to 4.5 and are depicted in Figures from 4.1 to 4.5. The analysis of variance of these characteristics is given in appendices I to V.

4.1.1 Physiological loss in weight (%)

The data on PLW of tomato fruits during storage were influenced by various packaging material, temperatures and their combinations presented in Tables 4.1, depicted in figure 4.1 and analysis of variance is given in Appendix-I.

Effect of Packaging material

It is clear from the data presented in Table 4.1 that PLW of tomato fruits increased with the advancement of storage duration but rate of increase in per cent weight loss was significantly affected by different packaging material during storage. On 10th day of storage, the minimum PLW was recorded in P_4 (0.93%) while maximum in P_1 (1.62%). Similarly, at the end of experimentation the minimum PLW was found in P_4 (2.05%) but, maximum in P_1 (2.51%) treatment and all the treatments were significantly differ with each other.

Effect of storage temperature

The tomato fruits stored at 6ºC (T_3) and 12ºC (T_2) temperature showed maximum storage life of 20th day whereas, at ambient storage temperature tomato fruits showed storage life of 10th day, On 10th day of storage the minimum PLW was recorded under treatment T_3 (1.17%) and maximum in control T_1 (1.50%) and the rate of increase in weight loss in all the treatments were significantly different with each other. Further, on 20th day, highest PLW was observed in T_3 (2.34%) and lower in T_2 (2.24%) treatments.

Combined effect of packaging material and storage temperature

The combined effects of packaging material and storage temperature on tomato fruits were found to be significant during entire period of storage. On 10th day of storage the lowest PLW was recorded in P_4T_3 (0.79%) treatment combination and highest in P_1T_1 (1.86%). Further, on 20th day of storage the minimum PLW was observed in P_4T_2 (1.98%) and highest in P_1T_2 (2.49%) treatment combinations.

4.1.2 Firmness (Newton)

The effects of various packaging materials, storage temperatures and their combinations on firmness of tomato fruits are presented in Tables 4.2 and depicted in Figures 4.2 and analysis of variance is given in Appendix- II.

Effect of packaging material

It is perusal from the data presented in Table 4.2 brought out that the firmness of tomato fruits decreased with the advancement of storage time during the entire period of experiment in all treatments. On 10th day of storage the maximum firmness was recorded in P_4 (46.48 N) while lowest in P_1 (40.36 N) and all treatments significantly different with each other. Similarly, at the end of experimentation the highest firmness was found in P_4 (42.65 N) but lowest in P_1 (30.11 N) treatment and P_1 treatment was at par with all other treatment.

Effect of storage temperature

A critical examination of data in temperature treatments reveal that firmness decreased under all three temperature treatments. At ambient storage temperature tomato fruits showed maximum storage life of 10 day whereas, at T_3 (6ºC) and T_2 (12ºC) temperature showed storage life of 20 day. On 10^{th} day of storage the superior firmness was recorded under treatment T_3 (45.39 N) and inferior in control T_1 (40 N) and all treatments were found to be significantly different with each other. Similarly, on 20^{th} day maximum firmness was recorded in T_2 (39.37 N) but minimum in T_2 (37.24 N) treatment.

Combined effect of packaging material and storage temperature

The combined effects of packaging material and storage temperature on firmness of tomato fruits were found to be significant during entire period of storage. On 10^{th} day of storage the highest firmness was recorded in P_4T_3 (48.16 N) treatment combination and lowest in P_1T_1 (35.52 N) and also found that the treatment combination P_1T_1 was at par with $P_2T_{1,}$ P_3T_2 and $P_2T_{3.}$ Similarly, on 20^{th} day, the maximum firmness was observed in P_4T_2 (44.18 N) but minimum in P_1T_2 (32.15 N) treatment combination and all treatment was found significantly different with each other.

4.1.3 Respiration rate (ml CO_2 kg^{-1} h^{-1})

The data on respiration rate of tomato fruits during storage as influenced by various packaging materials, temperatures and their combinations are being presented in Tables 4.3 and depicted in Figures 4.3 and analysis of variance is given in Appendix-III.

Effect of packaging materials

It is evident from the data presented in Table 4.3 that the tomato fruit showed a climacteric peak (the maximum point of respiration rate) on 5^{th} day of storage in all treatments. On 5^{th} day of storage the lowest respiration rate was found in P_4 (7.68 ml CO_2 kg^{-1} h^{-1}) treatment and highest in P_1 (12.19 ml CO_2 kg^{-1} h^{-1} whereas, on 20^{th} day of storage the maximum respiration rate was recorded in P_4 (8.01 ml CO_2 kg^{-1} h^{-1}) while minimum in P_1 (6.39 ml CO_2 kg^{-1} h^{-1}) and all treatments were found significantly differ with each other.

Effect of storage temperature

Tomato fruits stored at 6ºC (T_3) and 12ºC (T_2) temperature showed maximum storage life of 20th day whereas, at ambient storage temperature tomato fruits showed storage life of 10th day. On 5th day of storage the respiration rate is highest in T_1 (9.88 ml CO_2 kg^{-1} h^{-1}) treatment and lowest in T_3 (8.99 ml CO_2 kg^{-1} h^{-1}) treatment but on 20th day of storage the highest respiration rate was recorded under treatment T_2 (7.17 ml CO_2 kg^{-1} h^{-1}) and lowest in T_3 (6.92 ml CO_2 kg^{-1} h^{-1}) and all treatments was found significantly differ with each other.

Combined effect of packaging material and storage temperature

The combined effects of packaging material and storage temperature on respiration rate of tomato fruits were found to be significant during 5th and 10th day of storage but at 15th and 20th day of storage it was found to be non-significant. On 5th day of storage the respiration rate was highest in P_1T_1 (14.07 ml CO_2 kg^{-1} h^{-1}) treatment and minimum in P_4T_3 (7.55 ml CO_2 kg^{-1} h^{-1}) and also found that the all treatment combination found to be significant on 5th and 10th days of storage but on 15th and 20th days it was found it be non significant at all stages of observation taken during storage.

4.1.4 Ethylene evolution rate (µl C_2H_4 kg^{-1} h^{-1})

The data on ethylene evolution rate of tomato fruits as influenced by various packaging materials, temperatures and their combinations are presented in Tables 4.4, depicted in Figures 4.4 and analysis of variance is given in Appendix-IV.

Effect of packaging material

It is clear from the data presented in Table 4.4 that the ethylene evolution rate of tomato fruits showed a climacteric peak on 10th day of storage in all treatments. On 10th day of storage the highest ethylene evolution rate was recorded in P_1 (10.67 µl C_2H_4 kg^{-1} h^{-1}) treatment while lowest in P_4 (8.02 µl C_2H_4 kg^{-1} h^{-1}). Similarly on 20th day of storage the maximum ethylene production rate was found in P_4 (7.85 µl C_2H_4 kg^{-1} h^{-1}) and minimum P_1 (6.23 µl C_2H_4 kg^{-1} h^{-1}) treatment and all the treatments were significantly different with each other

Effect of storage temperature

The ethylene evolution rate of tomato fruit was significantly affected by storage temperature during entire period of storage. Fruit showed a climacteric peak on ambient temperature at 5th day of storage but fruit showed a climacteric peak on 10th day in T_2 (12ºC) and T_3 (6ºC) temperature treatments. On 10th day of storage the maximum ethylene evolution rate was recorded under treatment T_1 (10.83 µl C_2H_4 kg^{-1} h^{-1}) and minimum in T_1 (6.06 µl C_2H_4 kg^{-1} h^{-1}) and the rate of increase of ethylene evolution in all the treatments was found significantly different with each other. Similarly, on 20th day of storage highest ethylene evolution rate was observed in T_2 (7.01 µl C_2H_4 kg^{-1} h^{-1}) but lowest in T_3 (6.76 µl C_2H_4 kg^{-1} h^{-1}) treatments. During entire period of storage all treatment were observed significantly different except 15th days of storage.

Combined effect of packaging material and storage temperature

The combined effect of packaging material and storage temperature on ethylene evolution rate of tomato fruit was found to be significant during storage. On 5th day of storage the maximum ethylene evolution rate was recorded in P_1T_1 (9.97 µl C_2H_4 kg^{-1} h^{-1}) and minimum in P_4T_3 (4.95 µl C_2H_4 kg^{-1} h^{-1}) treatment combination and also found that the treatment combination P_2T_3 was at par with P_5T_3 treatment. Similarly, on 20th day the lowest ethylene evolution rate was observed in P_1T_3 (6.06 µl C_2H_4 kg^{-1} h^{-1}) and highest in P_4T_2 (7.96 µl C_2H_4 kg^{-1} h^{-1}) treatment combination.

4.1.5 Ripening Index (%)

The data on effect of different packaging material, storage temperatures and their combinations on ripening index of tomato fruits during storage are presented in Tables 4.5, depicted in Figure 4.5 and analysis of variance is given in Appendix-V.

Effect of packaging material

It is evident from the data presented in Table 4.5 that ripening index of tomato fruits increased with the advancement of storage period. The ripening index increased up to 15th day of storage and thereafter decreased on 20th day of storage in all the treatments and significant differences were occurred among all treatments. On 5th day of storage the highest ripening observed in treatment P_1 (9.04%) and lowest in P_4

(7.30%) treatment but at the end of experimentation the maximum ripening index observed in P_4 (9.24%) and minimum in P_1 (8.00%) treatments.

Effect of storage temperature

Data regarding ripening index showed that the highest ripening index was observed in T_1 (8.39%) and lowest in T_3 (7.52%) temperature treatment at 5th day of storage but at 20th day of storage the maximum ripening index was observed in T_2 (8.85%) and minimum in T_3 (8.13%) treatment and all treatments were found to be significantly differ with each other.

Combined effect of packaging material and storage temperature

The combined effects of packaging material and storage temperatures on ripening index of tomato fruits were found to be significantly different during entire period of storage. The highest ripening index observed in all treatment with higher temperature and ripening index decreased with decrease in storage temperature. At the 20th days fruit storage the maximum ripening index was observed in P_4T_2 (9.91%) and minimum in P_1T_3 (7.93%) treatment combination.

4.2 Biochemical characteristics

Data regarding the effect of different packaging material, storage temperature and their combinations on biochemical characteristics like TSS (ºB), acidity (%), ascorbic acid (mg $100g^{-1}$), total sugars (%), reducing sugar (%) and lycopene content during storage are presented in Tables 4.6 to 4.11 and are depicted in Figures from 4.6 to 4.1 and the analysis of variance of these characteristics is given in appendices- VI to XI.

4.2.1 Total soluble solids (ºB)

The data on TSS (ºB) of tomato fruit during storage at different temperatures as influenced by various packaging material, storage temperatures and their combinations are presented in Tables 4.6 depicted in figure 4.6 and analysis of variance is given in Appendix-VI.

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Effect of packaging material

It is clear from the data presented in Table 4.6 that TSS (ºB) of tomato fruits increased with the advancement of storage. The rate of increase in TSS (ºB) was significantly affected by different packaging materials. On 5th day of storage, the maximum TSS (5.06ºB) was recorded in P_1 while minimum in P_4 (4.60ºB) treatment. The treatment P_2 was found at par with P_3 and P_4 treatment. Further, at 20th day of storage the maximum TSS was found in P_4 (4.63ºB) treatment and minimum in P_1 (4.30ºB) treatments and all the treatments was noticed significantly differs with each other.

Effect of storage temperature

The highest TSS was recorded under treatment T_1 (5.17ºB) and minimum in T_3 (4.64ºB) on 5 day of storage of tomato fruits, and all treatments was found significantly different with each other. During storage all treatment found significantly different to each other except 20th days of storage through, on 20th day, maximum TSS was observed in T_2 (4.41ºB) and minimum in T_3 (4.38ºB) treatment.

Combined effect of packaging material and storage temperature

The combined effects of packaging materials and storage temperature on TSS of tomato fruits were found to be significant during storage except 20th day of storage. On 5 day of storage, the maximum TSS was recorded in P_1T_1 (5.40ºB) and minimum in P_4T_3 (4.48ºB) treatment combinations. Further, on 20 day of storage the highest TSS was observed in P_4T_2 (4.64ºB) and lowest in P_1T_3 (28ºB) treatment combinations.

4.2.2 Acidity (%)

The data on acidity of tomato fruits during storage is influenced by various packaging material, storage temperatures and their combinations are presented in Table 4.7, depicted in Figure 4.7 and analysis of variance is given in Appendix-VII.

Effect of packaging material

It is clear from the data presented in Table 4.7 that the acidity of tomato fruits decreased with the advancement of storage time during the entire period of experiment but rate of decrease in per cent was significantly affected by different packaging materials during experimentation. On 5th day of storage the maximum acidity was recorded in P_4 (0.64%) and minimum in P_1 (0.60%). Similarly, at the end of experimentation the lowest acidity was found in P_1 (0.35%) and highest in P_4 (0.50%) treatment and all the treatments were significantly different with each other.

Effect of storage temperature

Data presented in Table 4.7 showed the maximum acidity in T_2 (0.63%) and minimum in T_1 (0.57%) at 5th day of storage. While, on 20th day of storage the lowest acidity was observed in T_3 (0.44%) and highest acidity in T_2 (0.46%) treatment and all treatments found to be significantly differ with each other.

Combined effect of packaging material and storage temperature

The combined effects of packaging material and storage temperature on acidity of tomato fruits were found to be non-significant during entire period of storage. On 5th day of storage the minimum acidity was recorded in P_4T_1 (0.35%) and maximum in G_5T_3 (0.55%) treatment combination similarly on 20th day of storage the lowest acidity was observed in P_1T_2 (0.41%) and highest in P_4T_2 (0.51%) treatment combination.

4.2.3 Ascorbic acid (mg 100g^{-1})

The data related to effect of different packaging material, storage temperatures and their combinations on ascorbic acid content of tomato fruits during storage are presented in Tables 4.8, depicted in Figure 4.8, and analysis of variance is given in Appendix VIII.

Effect of packaging material

It is clear from the data presented in Table 4.8 that the ascorbic acid content was significantly affected by different packaging material during storage. On 5th day of storage the maximum ascorbic acid content was recorded in P_1 (33.89 mg 100g^{-1}) while lowest in P_4 (32.03 mg 100g^{-1}). Further, at the end of experimentation the minimum ascorbic acid content was found in P_1 (22.37 mg 100g^{-1}) and highest in P_4 (28.03 mg 100g^{-1}) treatment and P_1 treatment was found at par with P_4 treatment.

Effect of storage temperature

The minimum ascorbic acid content was observed at ambient storage temperature (30.34 mg $100g^{-1}$) and maximum in T_2 treatment (31.55 mg $100g^{-1}$) at 10^{th} day of storage. Further, on 20^{th} day of storage lowest ascorbic acid content was observed in T_3 (23.86 mg $100g^{-1}$) and highest in T_2 (25.41 mg $100g^{-1}$) treatment and all treatments were found to be significantly differ with each other.

Combined effect of packaging material and storage temperature

The combined effects of packaging material and storage temperatures on ascorbic acid content were found to be significant during entire period of storage. At 20^{th} day of storage the maximum ascorbic acid was found in P_4T_2 (29.82 mg $100g^{-1}$) and minimum in P_1T_3 (21.98 mg $100g^{-1}$) treatment combination (Table 4.8).

4.2.4 Total sugars (%)

The data on effect of different packaging material in package, storage temperatures and their combinations on total sugars of tomato fruits during storage are presented in Tables 4.9, depicted in Figures 4.9 and analysis of variance is given in Appendix-IX.

Effect of packaging material

It is evident from the data presented in Table 4.9 that the total sugars of tomato fruits increased up to 15^{th} day of storage in all the treatments and there after decrease on 20^{th} day of storage but the rate of change was significantly affected by different packaging materials during storage. On 5^{th} day of storage the lowest total sugars was recorded in P_4 (2.35%) and highest in P_1 (2.06 %). But at the end of experimentation the lowest total sugars was found in P_1 (2.48%) and highest in P_4 (2.91%) treatment.

Effect of storage temperature

Data regarding total sugars showed that the maximum total sugars was found in T_1 (2.53%) and minimum in T_3 (2.43%) temperature treatment at 5^{th} day of storage but at 20^{th} day of storage the highest total sugars was found in T_2 (2.77%) and lowest in T_3 (2.65%) treatment and all treatments were found to be significantly different with each other except on 15^{th} day of storage.

Combined effect of packaging materials and storage temperature

The significant differences among all treatment combinations were observed for total sugars of tomato fruits during entire period of storage 20^{th} day of storage. On 5^{th} day of storage the maximum total sugars was recorded in P_1T_1 (2.66%) treatment combination and minimum in P_4T_1 (2.08%) while on the 20^{th} day of storage the highest total sugar (3.01%) was recorded in P_4T_2 treatment and the lowest total sugar (2.46%) in P_1T_3 treatment.

4.2.5 Reducing sugar (%)

The data on effect of different packaging material, storage temperatures and their combinations on reducing sugar of tomato fruits during storage are presented in Tables 4.10, depicted in Figure 4.10 and analysis of variance is given in Appendix-X.

Effect of packaging material

It is evident from the data presented in Table 4.10 that reducing sugar of tomato fruits increased up to 15^{th} day of storage and thereafter decreased on 20^{th} day of storage in all the treatments and significant differences were occurred among all treatments. On 5^{th} day of storage the minimum reducing sugar was recorded in P_4 (1.87%) and maximum in P_1 (2.06%) treatment. At the end of experimentation the lowest reducing sugar was found in P_1 (1.63%) and highest in P_4 (1.97%) treatments.

Effect of storage temperature

Data regarding reducing sugar showed that the maximum reducing sugar was found in T_1 (2.01%) and minimum in T_3 (1.87%) temperature treatment at 5^{th} day of storage but at 20^{th} day of storage the highest reducing sugar was observed in T_2 (1.81%) and lowest in T_3 (1.70%) treatment and all treatments were found to be significantly differ with each other.

Combined effect of packaging material and storage temperature

The combined effects of packaging material and storage temperature on reducing sugar of tomato fruits were found to be significantly different during entire period of storage on 5^{th} day of storage the highest reducing sugar (2.11%) was noted in P_1T_1 treatment combination while the lowest reducing sugar (1.80%) in P_4T_3.

Further On 20th day of storage the maximum reducing sugar was recorded in P_4T_2 (2.00%) treatment combination and minimum in P_1T_3 (1.58%) treatment combination.

4.2.6 Lycopene (mg 100g^{-1})

The data on effect of different packaging materials and storage temperature and their combination on total sugars of tomato fruits during storage are presented in Tables 4.11, depicted in Figures 4.1 and analysis of variance is given in Appendix-XI.

Effect of packaging material

It is evident from the data presented in Table 4.25 that the lycopene content of tomato fruits increased up to 20th day of storage in all the treatments and the rate of change was significantly affected by different packaging materials during storage. On 5th day of storage the minimum lycopene content (mg 100g^{-1}) was recorded in P_4 (3.02 mg 100g^{-1}) and maximum in P_1 (3.29 mg 100g^{-1}). But at the end of experimentation the lowest lycopene content was found in P_3 (4.18 mg 100g$^{-1)}$ and maximum in P_4 (4.53 mg 100g^{-1}) treatment.

Effect of storage temperature

Data regarding total sugars showed that the maximum lycopene content was found in T_1 (3.29 mg 100g^{-1}) and minimum in T_3 (2.86 mg 100g^{-1}) temperature treatment at 5th day of storage but at 20th day of storage the highest lycopene content was found in T_2 (4.37 mg 100g^{-1}) and lowest in T_3 (4.21 mg 100g^{-1}) treatment and all treatments were found to be significantly different with each other except on 15th days of storage.

Combined effect of packaging materials and storage temperature

The significant differences among all treatment combinations were observed for lycopene content of tomato fruits during entire period of storage except 15 day of storage. On 5th day of storage the maximum lycopene content was recorded in P_1T_1 (3.59 mg 100g^{-1}) treatment combination and minimum in P_4T_3 (2.80 mg 100g^{-1}). But at 20th days of storage the highest lycopene content was found in P_4T_2 (4.60 mg 100 g^{-1}) and lowest in treatment P_3T_3 (3.96 mg 100g^{-1}).

4.3 Color and sensory evaluation

The data on decay (%), Hunter color coordinates (L^*, a^* and b^*), over all organoleptic score and chilling injury index (out of 5 marks) of tomato fruits during storage as influenced by different packaging materials, different storage temperatures and their combinations are presented in the Tables 4.12 to 4.17, depicted in Figures from 4.12 to 4.17 and analysis of variance in Appendix from XII to XVII.

4.1.1 Decay (%)

The data on decay (%) of tomato fruits during storage were influenced by various packaging material, temperatures and their combinations presented in Tables 4.12, depicted in Figure 4.12 and analysis of variance is given in Appendix-XII.

Effect of packaging material

It is clear from the data presented in Table 4.12 that decay (%) of tomato fruits increased with the advancement of storage duration but rate of increase in decay per cent was significantly affected by different packaging material during storage. On 5^{th} day of storage, the minimum decay was recorded in P_4 (1.40%) while maximum in P_1 (3.69%). Similarly, at the end of experimentation the lowest decay was found in P_4 (13.44%) but highest in P_1 (16.72%) treatment and all the treatments were significantly differ with each other.

Effect of storage temperature

The tomato fruits stored at 6ºC (T_3) and 12ºC (T_2) temperature showed maximum storage life of 20^{th} day whereas, at ambient storage temperature tomato fruits showed storage life of 10^{th} day, Only 5th day of storage the minimum decay was recorded under treatment T_3 (2.14%) and maximum in control T_1 (3.96%) and the rate of increase in decay per cent in all the treatments were significantly different with each other. Further, on 20^{th} day, highest decay percent was observed in T_3 (16.87%) and lowest in T_2 (13.65%) treatments.

Combined effect of packaging material and storage temperature

The combined effects of packaging material and storage temperature on tomato fruits were found to be significant during entire period of storage. On 5^{th} day of storage the minimum decay per cent was recorded in P_4T_3 (1.02%) treatment combination and maximum in P_1T_1 (5.02%). Further, on 20th day of storage the lowest decay per cent was observed in P_4T_2 (11.21%) and highest in P_1T_3 (18.18%) treatment combinations.

4.3.2 CIE L^* color coordinate (luminosity or lightness)

The data on color coordinates for luminosity or lightness (L^*) of tomato fruits during storage as influenced by various packaging materials , temperatures and their combinations are presented in Tables 4.13.1 depicted in Figures 4.131 and analysis of variance is given in Appendix- XIII.

Effect of gaseous composition

A perusal of data presented in Table 4.13 reveal that the color coordinate L^* of tomato fruits increased with the advancement of storage time during the entire period of experiment but rate of change was significantly affected by different packaging materials during storage. On 5th day of storage the maximum luminosity (L^*) was recorded in P_1 (36.80) while minimum in P_4 (27.36) further, at the end of experimentation the highest L^* value was found in P_1 (45.69) and lowest in P_4 (33.80) treatments.

Effect of storage temperature

Data presented in Table 4.13.1 show that the L^* value of tomato fruits increased with the advancement of storage period. On 5th day of storage the maximum luminosity (L^*) was recorded under treatment T_1 (33.34) and minimum in T_3 (30.44) and all treatments were found significantly different with each other. But, at 20th day the highest L^* value was observed in T_3 (41.43) and lowest in T_2 (37.28) treatments and both treatments were significantly different with each other.

Combined effect of packaging material and storage temperature

The combined effects of packaging material and storage temperatures on color coordinate L^* of tomato fruits were found to be significant during entire period of storage. On 5th day of storage the maximum color coordinate L^* value was recorded in P_1T_1 (38.37) treatment combination and minimum in P_4T_3 (26.03). Further, on 20th

day of storage, the highest color coordinate L^* value was observed in P_1T_2 (44.92) and lowest in P_5T_2 (30.58) treatment combination.

4.3.3 CIE a^* color coordinate (green-red axis)

The data on CIE a^* color coordinate of tomato fruits during storage as affected by various packaging materials, storage temperatures and their combinations are presented in Tables 4.13.2, depicted in Figure 4.13.2 and analysis of variance is given in Appendix- XIV.

Effect of packaging material

It is clear from the data presented in Table 4.13.2 that CIE a^* color coordinate of tomato fruits increased with the advancement of storage time. On 5th day of storage the maximum CIE a^* color coordinate was recorded in P_1 (11.92) while minimum in P_4 (9.15). Similarly, at the end of experimentation the highest CIE a^* color coordinate was found in P_1 (19.78) and lowest in P_4 (13.43) treatment.

Effect storage temperature

The data present in Table 4.13.2 show that the maximum CIE a^* color value on 5th day was found in T_1 (11.48) treatment and minimum in T_3 (9.45) treatment. While, on 20th day, higher value of CIE a^* color coordinate was observed in T_3 (16.32) in comparison to T_2 (15.96) treatments and both treatment were found to be significant different with each other.

Combined effect of packaging material and storage temperature

The combined effect of packaging material land storage temperature on CIE a^* color coordinate of tomato fruits were found to be significant during entire period of storage. On 5th day of storage the maximum CIE a^* color coordinate was recorded in P_1T_1 (13.65) treatment combination and minimum in P_4T_3 (8.81) while at 20th day of storage the highest CIE a^* color coordinate was observed in P_1T_3 (19.82) and lowest in P_4T_2 (13.41) treatment combination.

4.3.4 CIE b^* color coordinate

The data on CIE b^* color coordinate of tomato fruits during storage as influenced by various packaging materials, temperatures and their combinations are presented in Tables 4.13.3, depicted in Figure 4.13.3 and analysis of variance is given in Appendix- XV.

Effect of packaging material

It is clear from the data presented in Table 4.13.3 that the CIE b^* color coordinate of tomato fruits increased with the advancement of storage time during the entire period of experimentation but rate of increased in CIE b^* color coordinate was significantly affected by different packaging materials during storage. On 5th day of storage the minimum CIE b^* color coordinate was recorded in P_4 (15.71) while maximum in P_1 (20.77). Similarly, at the end of experimentation the lowest CIE b^* color coordinate was found in P_4 (28.90) and highest in P_1 (37.48) treatment.

Effect of storage temperature

The tomato fruits stored at 6ºC (T_3) and 12ºC (T_2) temperature showed maximum storage life of 20th day whereas, at ambient storage temperature tomato fruits showed storage life of 10th day. On 5th day of storage the minimum CIE b^* color coordinate was recorded under treatment T_3 (16.77) and maximum in control T_1 (20.41). Whereas at the end of storage period, lower CIE b^* color coordinate was observed in T_2 (33.28) in comparison to T_3 (33.78) treatment and both the treatments were significantly different with each other.

Combined effect of packaging material land storage temperature

The combined effect of packaging materials and storage temperature of tomato fruits were found to be significant during entire period of storage. On 5th day of storage the minimum CIE b^* color coordinate was recorded in P_4T_3 (14.23) treatment combination and maximum in P_1T_1 (23.68) treatment combination. While, on 20th day, the lowest CIE a^* color coordinate was observed in P_4T_2 (28.62) and highest in P_1T_2 (38.46) treatment combination and all treatments were found to be significant during storage.

4.3.5 Overall organoleptic score (out of 10 marks)

The data on overall organoleptic score of tomato fruits during storage as influenced by various packaging materials, temperatures and their combinations are presented in Tables 4.14, depicted in Figure 4.14 and analysis of variance is given in Appendix- XVI.

Effect of packaging material

It is evident from the data presented in Table 4.14 on over all organoleptic score showed that the maximum overall organoleptic score was observed in P_1 (5.93) and minimum in P_4 (5.75) on 5^{th} day of storage. Whereas, at the end of experimentation the lowest overall organoleptic score was found in P_1 (4.96) and highest in P_4 (5.65) treatment and all treatments were found to be significantly differing with each other.

Effect of storage temperature

Data regarding over all organoleptic score showed that the maximum over all organoleptic score was recorded in T_1 (6.17) and minimum in T_3 (5.64) temperature treatment at 5^{th} day of storage but at 20^{th} day of storage the higher overall organoleptic score was observed in T_2 (5.40) and minimum in T_3 (5.10) treatments and both treatment were noted significantly different with each other

Combined effect of packaging material and storage temperature

The combined effect of packaging material and storage temperature on over all organoleptic score of tomato fruits were found to be significant during entire period of storage. On 5^{th} day of storage the maximum over all organoleptic score was recorded in P_1T_1 (6.25) treatment combination and minimum in P_4T_3 (5.52), while at 20^{th} day of storage highest overall organoleptic score was recorded in P_4T_2 (5.84) and lowest in P_1T_3 (489) treatment combination and all treatment combinations were found to be significantly different with each other.

4.3.6 Chilling injury index (out of 5 marks)

The data on chilling injury index of tomato fruits during storage as affected by different packaging material, storage temperatures and their combinations are presented in the Tables 4.15, depicted in Figure 4.15 and analysis of variance in Appendix- XVII.

Effect of packaging material

It is clear from the data that the chilling injury symptoms were occurs after 10th day of storage but the maximum chilling injury index (out of 5 marks) observed in p_1 (0.24) treatment and minimum in P_4 (0.06) treatment 15th day of storage. Similarly at 20th day of storage highest chilling injury symptoms were occurs in p_1 (1.91) and lowest in p_4 (0.98) treatment.

Effect of storage temperature

It is evident from the same table4.15 that the storage temperature significantly affected chilling injury during storage except 5th and 10th day of storage because chilling injury was not seen on 5th and 10th day of storage in all the treatments. On 15th day, the chilling injury index was observed maximum in T_3 (0.81) treatment and minimum in T_2 (0.11) treatment further at 20th day of storage the highest chilling injury index was found in T_3 (2.07) and lowest in T_2 (1.10) treatment. And both treatment are significantly differ with each other.

Combined effect of packaging material and storage temperature

The combined effect of packaging material and storage temperature were significantly affected chilling injury during storage except 5th and 10th day of storage because chilling injury was not seen on 5th and 10th day of storage in all the treatment combinations. On 15 day of storage the maximum chilling injury index was observed in p_1T_3 (0.26) treatment and minimum p_4T_2 (0.00) whereas at 20th day of storage the highest chilling injury index was observed in p_1T_3 (2.56) and minimum in p_4T_2 (0.95) treatment combination.

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Table 4.1 Effect of packaging material and storage temperature on PLW (%) of tomato fruit during storage

Treatment		Storage day			
		5	**10**	**15**	**20**
Packaging material					
P_1 (Control)		1.45	1.62	2.10	2.51
P_2 (20 µ LDPE Bag)		1.29	1.40	1.85	2.36
P_3 (40 µ LDPE Bag)		1.23	1.37	1.31	2.31
P_4 (60 µ LDPE Bag)		0.76	0.93	1.12	2.05
P_5 (80 µ LDPE Bag)		1.08	1.21	1.30	2.21
SEm±		0.010	0.010	0.007	0.011
CD (P=0.05)		0.020	0.020	0.021	0.033
Storage temperature (ºC)					
T_1(AmbientTemp.10ºC- 32.5ºC)		1.33	1.50	-	-
T_2 (12ºC)		1.12	1.25	1.65	2.24
T_3 (6ºC)		1.04	1.17	1.41	2.34
SEm±		0.003	0.003	0.005	0.007
CD (P=0.05)		0.010	0.010	0.014	0.021
Packaging material X Storage temperature					
T_1	P_1T_1	1.61	1.86	-	-
T_2	P_2T_1	1.40	1.58	-	-
T_3	P_3T_1	1.45	1.63	-	-
T_4	P_4T_1	0.91	1.01	-	-
T_5	P_5T_1	1.26	1.42	-	-
T_6	P_1T_2	1.41	1.53	2.31	2.49
T_7	P_2T_2	1.25	1.33	1.98	2.31
T_8	P_3T_2	1.21	1.28	1.39	2.28
T_9	P_4T_2	0.71	0.98	1.21	1.98
T_{10}	P_5T_2	1.01	1.13	1.37	2.13
T_{11}	P_1T_3	1.32	1.46	1.88	2.53
T_{12}	P_2T_3	1.21	1.28	1.71	2.41
T_{13}	P_3T_3	1.03	1.21	1.23	2.33
T_{14}	P_4T_3	0.65	0.79	1.02	2.12
T_{15}	P_5T_3	0.97	1.09	1.22	2.29
SEm±		0.009	0.010	0.012	0.019
CD (P=0.05)		0.026	0.030	0.037	0.056

'—' denotes no fruits under treatments at 15 and 20 days of storage.

Note: Initial value of fresh tomato fruits = 0%

Table 4.2 Effect of packaging material and storage temperature on firmness (Newton) of tomato fruit during storage

Treatment		Storage day			
		5	10	15	20
Packaging material					
P_1 (Control)		44.05	40.36	38.79	30.11
P_2 (20 µ LDPE Bag)		46.16	42.31	41.87	38.84
P_3 (40 µ LDPE Bag)		47.14	43.44	43.41	39.65
P_4 (60 µ LDPE Bag)		49.20	46.48	46.08	42.65
P_5 (80 µ LDPE Bag)		47.80	44.71	44.07	40.29
SEm±		0.21	0.20	0.18	0.16
CD (P=0.05)		0.62	0.58	0.52	0.47
Storage temperature (ºC)					
T_1(AmbientTemp.10ºC-32.5ºC)		47.52	40.00	-	-
T_2 (12ºC)		46.21	44.98	42.52	39.37
T_3 (6ºC)		46.87	45.39	43.16	37.24
SEm±		0.14	0.13	0.12	0.10
CD (P=0.05)		0.40	0.38	0.34	0.31
Packaging material X Storage temperature					
T_1	P_1T_1	45.10	35.52	-	-
T_2	P_2T_1	46.77	38.56	-	-
T_3	P_3T_1	47.90	40.33	-	-
T_4	P_4T_1	49.52	44.13	-	-
T_5	P_5T_1	48.32	41.47	-	-
T_6	P_1T_2	43.16	42.44	38.43	32.15
T_7	P_2T_2	45.69	44.13	41.55	39.23
T_8	P_3T_2	46.42	44.98	43.25	40.15
T_9	P_4T_2	48.56	47.14	45.63	44.18
T_{10}	P_5T_2	47.24	46.23	43.72	41.15
T_{11}	P_1T_3	43.88	43.12	39.14	28.06
T_{12}	P_2T_3	46.01	44.25	42.19	38.45
T_{13}	P_3T_3	47.11	45.01	43.56	39.14
T_{14}	P_4T_3	49.52	48.16	46.52	41.12
T_{15}	P_5T_3	47.85	46.42	44.41	39.42
SEm±		0.37	0.35	0.30	0.28
CD (P=0.05)		1.07	1.01	0.90	0.82

'—' denotes no fruits under treatments at 15 and 20 days of storage.

Note: Initial value of fresh tomato fruits = 39.78 N

Table 4.3 Effect of packaging material and storage temperature on respiration rate ($ml\ CO_2\ kg^{-1}\ h^{-1}$) of tomato fruit during storage

Treatment		Storage day 5	10	15	20
Packaging material					
P_1 (Control)		12.19	12.73	9.05	6.39
P_2 (20 µ LDPE Bag)		9.95	11.04	8.81	6.81
P_3 (40 µ LDPE Bag)		8.89	10.32	9.15	7.39
P_4 (60 µ LDPE Bag)		7.68	9.56	9.55	8.01
P_5 (80 µ LDPE Bag)		8.08	10.30	8.10	6.64
SEm±		0.04	0.05	0.09	0.04
CD (P=0.05)		0.12	0.15	0.25	0.12
Storage temperature (ºC)					
T_1(AmbientTemp.10ºC- 32.5ºC 10ºC)		9.88	9.11	-	-
T_2 (12ºC)		9.21	11.87	8.98	7.17
T_3 (6ºC)		8.99	11.39	8.88	6.92
SEm±		0.03	0.03	0.06	0.03
CD (P=0.05)		0.08	0.10	NS	0.084
Packaging material X Storage temperature					
T_1	P_1T_1	14.07	11.63	-	-
T_2	P_2T_1	10.25	9.07	-	-
T_3	P_3T_1	9.03	8.97	-	-
T_4	P_4T_1	7.90	7.85	-	-
T_5	P_5T_1	8.15	8.01	-	-
T_6	P_1T_2	11.58	13.61	9.06	6.55
T_7	P_2T_2	9.82	12.11	8.88	6.90
T_8	P_3T_2	8.93	11.14	9.24	7.56
T_9	P_4T_2	7.60	10.95	9.58	8.12
T_{10}	P_5T_2	8.10	11.55	8.14	6.74
T_{11}	P_1T_3	10.91	12.96	9.03	6.22
T_{12}	P_2T_3	9.78	11.95	8.73	6.72
T_{13}	P_3T_3	8.70	10.85	9.05	7.22
T_{14}	P_4T_3	7.55	9.88	9.51	7.89
T_{15}	P_5T_3	7.99	11.33	8.06	6.55
SEm±		0.07	0.09	0.19	0.08
CD (P=0.05)		0.21	0.25	0.44	0.22

'—' denotes no fruits under treatments at 15 and 20 days of storage

Note: Initial value of fresh tomato fruits = 6.38 ($ml\ CO_2\ kg^{-1}\ h^{-1}$)

Table 4.4 Effect of packaging material and storage temperature on Ethylene (µl C_2H_4 Kg $^{-1}$ h^{-1}) of tomato fruit during storage

Treatment		Storage day			
		5	10	15	20
Packaging material					
P_1 (Control)		8.09	10.67	8.82	6.23
P_2 (20 µ LDPE Bag)		6.75	9.28	8.58	6.65
P_3 (40 µ LDPE Bag)		6.09	8.69	8.92	7.23
P_4 (60 µ LDPE Bag)		5.07	8.02	9.32	7.85
P_5 (80 µ LDPE Bag)		5.48	8.74	7.87	6.49
SEm±		0.05	0.04	0.04	0.03
CD (P=0.05)		0.14	0.13	0.12	0.10
Storage temperature (ºC)					
T_1(AmbientTemp.10ºC- 32.5ºC)		6.81	6.06	-	-
T_2 (12ºC)		6.15	10.83	8.65	7.01
T_3 (6ºC)		5.93	10.35	8.75	6.76
SEm±		0.03	0.03	0.03	0.02
CD (P=0.05)		0.09	0.08	NS	0.07
Packaging material X Storage temperature					
T_1	P_1T_1	9.97	7.53	-	-
T_2	P_2T_1	7.05	5.87	-	-
T_3	P_3T_1	6.23	6.17	-	-
T_4	P_4T_1	5.25	5.30	-	-
T_5	P_5T_1	5.55	5.41	-	-
T_6	P_1T_2	7.48	12.57	8.80	6.39
T_7	P_2T_2	6.62	11.07	8.50	6.74
T_8	P_3T_2	6.13	10.10	8.82	7.40
T_9	P_4T_2	5.00	9.91	9.28	7.96
T_{10}	P_5T_2	5.50	10.51	7.83	6.58
T_{11}	P_1T_3	6.81	11.92	8.83	6.06
T_{12}	P_2T_3	6.58	10.91	8.65	6.56
T_{13}	P_3T_3	5.90	9.81	9.01	7.06
T_{14}	P_4T_3	4.95	8.84	9.35	7.73
T_{15}	P_5T_3	5.39	10.29	7.91	6.39
SEm±		0.08	0.08	0.07	0.06
CD (P=0.05)		0.24	0.22	0.21	0.17

'—' denotes no fruits under treatments at 15 and 20 days of storage.

Note: Initial value of fresh tomato fruits = 0.01 (µl C_2H_4 Kg $^{-1}$ h^{-1})

Table 4.5 Effect of packaging material and storage temperature on ripening index (%) of tomato fruit during storage

Treatment		**Storage day**			
		5	**10**	**15**	**20**
Packaging material					
P_1 (Control)		9.04	10.49	10.46	8.00
P_2 (20 µ LDPE Bag)		8.14	9.02	9.78	8.39
P_3 (40 µ LDPE Bag)		7.74	8.67	9.07	8.36
P_4 (60 µ LDPE Bag)		7.30	7.77	8.60	9.24
P_5 (80 µ LDPE Bag)		7.55	8.35	9.00	8.47
SEm±		0.04	0.04	0.0 5	0.04
CD (P=0.05)		0.11	0.12	0.13	0.12
Storage temperature (ºC)					
T_1 (Ambient Temp 10ºC□ 32.5ºC)		8.39	9.46	-	-
T_2 (12ºC)		7.94	8.73	9.52	8.85
T_3 (6ºC)		7.52	8.39	9.24	8.13
SEm±		0.03	0.03	0.03	0.03
CD (P=0.05)		0.07	0.08	0.09	0.08
Packaging material X Storage temperature					
T_1	P_1T_1	9.77	11.31	-	-
T_2	P_2T_1	8.74	9.60	-	-
T_3	P_3T_1	8.07	9.58	-	-
T_4	P_4T_1	7.46	8.01	-	-
T_5	P_5T_1	7.93	8.79	-	-
T_6	P_1T_2	8.90	10.38	10.53	8.06
T_7	P_2T_2	7.99	8.75	10.16	8.79
T_8	P_3T_2	7.79	8.36	9.13	8.69
T_9	P_4T_2	7.44	7.84	8.67	9.91
T_{10}	P_5T_2	7.60	8.34	9.11	8.81
T_{11}	P_1T_3	8.44	9.77	10.38	7.93
T_{12}	P_2T_3	7.68	8.71	9.39	7.99
T_{13}	P_3T_3	7.37	8.07	9.01	8.03
T_{14}	P_4T_3	7.01	7.46	8.52	8.56
T_{15}	P_5T_3	7.12	7.93	8.88	8.12
SEm±		0.07	0.07	0.08	0.07
CD (P=0.05)		0.19	0.20	0.23	0.21

'—' denotes no fruits under treatments at 15 and 20 days of storage.

Note: Initial value of fresh tomato fruits = 5.27%

Table 4.6 Effect of packaging material and storage temperature on TSS (%) of tomato fruit during storage

Treatment		Storage day			
		5	10	15	20
Packaging material					
P_1 (Control)		5.06	5.01	4.52	4.30
P_2 (20 µ LDPE Bag)		4.94	4.84	4.55	4.33
P_3 (40 µ LDPE Bag)		4.85	4.69	4.66	4.44
P_4 (60 µ LDPE Bag)		4.60	5.04	4.85	4.63
P_5 (80 µ LDPE Bag)		4.72	4.65	4.53	4.31
SEm±		0.02	0.02	0.02	0.02
CD (P=0.05)		0.06	0.06	0.07	0.06
Storage temperature (ºC)					
T_1 (Ambient Temp 10ºC 32.5ºC)		5.17	4.51	-	-
T_2 (12ºC)		4.71	5.18	4.75	4.41
T_3 (6ºC)		4.64	4.87	4.49	4.38
SEm±		0.01	0.01	0.01	0.01
CD (P=0.05)		0.04	0.04	0.04	NS
Packaging material X Storage temperature					
T_1	P_1T_1	5.40	4.67	-	-
T_2	P_2T_1	5.31	4.50	-	-
T_3	P_3T_1	5.29	4.35	-	-
T_4	P_4T_1	4.82	4.70	-	-
T_5	P_5T_1	5.01	4.31	-	-
T_6	P_1T_2	4.97	5.34	4.65	4.31
T_7	P_2T_2	4.80	5.17	4.68	4.34
T_8	P_3T_2	4.65	5.02	4.79	4.45
T_9	P_4T_2	4.50	5.37	4.98	4.64
T_{10}	P_5T_2	4.61	4.98	4.66	4.32
T_{11}	P_1T_3	4.82	5.03	4.39	4.28
T_{12}	P_2T_3	4.72	4.86	4.42	4.31
T_{13}	P_3T_3	4.61	4.71	4.53	4.42
T_{14}	P_4T_3	4.48	5.06	4.72	4.61
T_{15}	P_5T_3	4.55	4.67	4.40	4.29
SEm±		0.04	0.04	0.04	0.04
CD (P=0.05)		0.11	0.11	0.11	0.11

'—' denotes no fruits under treatments at 15 and 20 days of storage.

Note: Initial value of fresh tomato fruits = 5.52%

Table 4.7 Effect of packaging material and storage temperature on acidity (%) of tomato fruit during storage

Treatment		Storage day			
		5	**10**	**15**	**20**
Packaging material					
P_1 (Control)		0.60	0.54	0.51	0.41
P_2 (20 μ LDPE Bag)		0.61	0.54	0.53	0.43
P_3 (40 μ LDPE Bag)		0.62	0.54	0.53	0.44
P_4 (60 μ LDPE Bag)		0.64	0.59	0.53	0.50
P_5 (80 μ LDPE Bag)		0.63	0.55	0.53	0.47
SEm±		0.003	0.003	0.002	0.002
CD (P=0.05)		0.010	0.010	0.007	0.005
Storage temperature (ºC)					
T_1 (Ambient Temp 10ºC□ 32.5ºC)		0.57	0.51	-	-
T_2 (12ºC)		0.63	0.55	0.54	0.46
T_3 (6ºC)		0.62	0.54	0.53	0.44
SEm±		0.003	0.003	0.001	0.001
CD (P=0.05)		0.010	0.009	0.004	0.004
Packaging material X Storage temperature					
T_1	P_1T_1	0.59	0.49	-	-
T_2	P_2T_1	0.58	0.50	-	-
T_3	P_3T_1	0.58	0.52	-	-
T_4	P_4T_1	0.55	0.53	-	-
T_5	P_5T_1	0.57	0.50	-	-
T_6	P_1T_2	0.61	0.57	0.51	0.41
T_7	P_2T_2	0.62	0.56	0.53	0.44
T_8	P_3T_2	0.63	0.59	0.54	0.46
T_9	P_4T_2	0.65	0.61	0.59	0.51
T_{10}	P_5T_2	0.64	0.55	0.53	0.47
T_{11}	P_1T_3	0.60	0.57	0.50	0.40
T_{12}	P_2T_3	0.62	0.55	0.52	0.42
T_{13}	P_3T_3	0.62	0.54	0.53	0.42
T_{14}	P_4T_3	0.64	0.58	0.52	0.49
T_{15}	P_5T_3	0.63	0.52	0.52	0.46
SEm±		0.004	0.004	0.004	0.003
CD (P=0.05)		0.014	0.012	0.011	0.009

'—' denotes no fruits under treatments at 15 and 20 days of storage.

Note: Initial value of fresh tomato fruits = 0.68%

Table 4.8 Effect of packaging material and storage temperature on Ascorbic acid (mg/100g) of tomato fruit during storage

Treatment		Storage day			
		5	**10**	**15**	**20**
Packaging material					
P_1 (Control)		33.89	30.78	28.06	22.37
P_2 (20 µ LDPE Bag)		33.39	30.88	28.64	23.90
P_3 (40 µ LDPE Bag)		32.74	31.16	29.75	24.27
P_4 (60 µ LDPE Bag)		32.03	31.41	30.82	28.03
P_5 (80 µ LDPE Bag)		33.01	31.25	29.89	24.61
SEm±		0.15	0.13	0.12	0.10
CD (P=0.05)		0.43	0.37	0.36	0.30
Storage temperature (ºC)					
T_1 (Ambient Temp 10ºC□ 32.5ºC)		33.53	30.34	-	-
T_2 (12ºC)		33.24	31.55	29.67	25.41
T_3 (6ºC)		32.27	31.39	29.18	23.86
SEm±		0.10	0.08	0.08	0.07
CD (P=0.05)		0.28	0.24	0.23	0.20
Packaging material X Storage temperature					
T_1	P_1T_1	34.75	27.46	-	-
T_2	P_2T_1	33.61	30.05	-	-
T_3	P_3T_1	33.54	31.02	-	-
T_4	P_4T_1	32.09	32.12	-	-
T_5	P_5T_1	33.66	31.06	-	-
T_6	P_1T_2	33.78	32.55	28.60	22.75
T_7	P_2T_2	33.52	31.41	29.03	24.34
T_8	P_3T_2	33.13	31.34	29.82	24.98
T_9	P_4T_2	32.01	31.01	30.86	29.82
T_{10}	P_5T_2	33.74	31.46	30.06	25.14
T_{11}	P_1T_3	33.14	32.32	27.51	21.98
T_{12}	P_2T_3	33.05	31.18	28.24	23.45
T_{13}	P_3T_3	31.56	31.11	29.68	23.56
T_{14}	P_4T_3	31.98	31.09	30.78	26.23
T_{15}	P_5T_3	31.62	31.23	29.71	24.07
SEm±		0.26	0.22	0.21	0.18
CD (P=0.05)		0.75	0.64	0.62	0.52

'—' denotes no fruits under treatments at 15 and 20 days of storage.

Note: Initial value of fresh tomato fruits = 29.17 (mg/100g)

Table 4.9 Effect of packaging material and storage temperature on total sugar (%) of tomato fruit during storage

Treatment		Storage day			
		5	10	15	20
Packaging material					
P_1 (Control)		2.60	2.83	3.10	2.48
P_2 (20 µ LDPE Bag)		2.56	2.77	3.14	2.70
P_3 (40 µ LDPE Bag)		2.54	2.73	3.13	2.73
P_4 (60 µ LDPE Bag)		2.35	2.51	3.46	2.91
P_5 (80 µ LDPE Bag)		2.43	2.62	3.04	2.75
SEm±		0.01	0.01	0.02	0.03
CD (P=0.05)		0.03	0.04	0.06	0.08
Storage temperature (ºC)					
T_1 (Ambient Temp 10ºC□ 32.5ºC)		2.43	2.85	-	-
T_2 (12ºC)		2.53	2.63	3.17	2.77
T_3 (6ºC)		2.52	2.59	3.17	2.65
SEm±		0.01	0.01	0.01	0.02
CD (P=0.05)		0.02	0.02	NS	0.05
Packaging material X Storage temperature					
T_1	P_1T_1	2.66	3.08	-	-
T_2	P_2T_1	2.57	2.99	-	-
T_3	P_3T_1	2.55	2.97	-	-
T_4	P_4T_1	2.08	2.50	-	-
T_5	P_5T_1	2.27	2.69	-	-
T_6	P_1T_2	2.58	2.71	3.09	2.49
T_7	P_2T_2	2.56	2.69	3.12	2.79
T_8	P_3T_2	2.53	2.63	3.09	2.77
T_9	P_4T_2	2.49	2.53	3.50	3.01
T_{10}	P_5T_2	2.51	2.61	3.07	2.78
T_{11}	P_1T_3	2.57	2.69	3.10	2.46
T_{12}	P_2T_3	2.54	2.63	3.15	2.61
T_{13}	P_3T_3	2.53	2.58	3.16	2.68
T_{14}	P_4T_3	2.48	2.50	3.42	2.81
T_{15}	P_5T_3	2.50	2.57	3.01	2.71
SEm±		0.02	0.02	0.03	0.05
CD (P=0.05)		0.06	0.06	0.10	0.14

'—' denotes no fruits under treatments at 15 and 20 days of storage.

Note: Initial value of fresh tomato fruits = 1.90%

Table 4.10 Effect of packaging material and storage temperature on reducing sugar (%) of tomato fruit during storage

Treatment		Storage day			
		5	10	15	20
Packaging material					
P_1 (Control)		2.06	2.11	2.17	1.63
P_2 (20 µ LDPE Bag)		1.95	2.06	2.12	1.69
P_3 (40 µ LDPE Bag)		1.92	2.01	2.04	1.74
P_4 (60 µ LDPE Bag)		1.87	1.96	2.09	1.97
P_5 (80 µ LDPE Bag)		1.91	2.00	2.08	1.75
SEm±		0.01	0.01	0.01	0.01
CD (P=0.05)		0.03	0.03	0.03	0.02
Storage temperature (ºC)					
T_1 (Ambient Temp 10ºC□ 32.5ºC)		2.01	2.07		
T_2 (12ºC)		1.95	2.03	2.14	1.81
T_3 (6ºC)		1.87	1.98	2.05	1.70
SEm±		0.01	0.01	0.01	0.01
CD (P=0.05)		0.02	0.02	0.03	0.01
Packaging material X Storage temperature					
T_1	P_1T_1	2.11	2.16	-	-
T_2	P_2T_1	2.03	2.11	-	-
T_3	P_3T_1	1.98	2.05	-	-
T_4	P_4T_1	1.92	2.01	-	-
T_5	P_5T_1	1.99	2.04	-	-
T_6	P_1T_2	2.06	2.13	2.21	1.68
T_7	P_2T_2	1.96	2.06	2.14	1.76
T_8	P_3T_2	1.94	2.01	2.06	1.81
T_9	P_4T_2	1.88	1.96	2.18	2.00
T_{10}	P_5T_2	1.92	2.00	2.12	1.78
T_{11}	P_1T_3	2.01	2.05	2.13	1.58
T_{12}	P_2T_3	1.87	2.00	2.09	1.62
T_{13}	P_3T_3	1.85	1.96	2.01	1.67
T_{14}	P_4T_3	1.80	1.92	2.00	1.94
T_{15}	P_5T_3	1.82	1.95	2.03	1.71
SEm±		0.02	0.02	0.02	0.01
CD (P=0.05)		0.04	0.04	0.04	0.04

'—' denotes no fruits under treatments at 15 and 20 days of storage.

Note: Initial value of fresh tomato fruits = 1.56%

Table 4.11 Effect of packaging material and storage temperature on lycopene (mg $100g^{-1}$) of tomato fruit during storage

Treatment		Storage day			
		5	10	15	20
Packaging material					
P_1 (Control)		3.29	3.91	4.25	4.31
P_2 (20 µ LDPE Bag)		3.13	3.62	3.95	4.26
P_3 (40 µ LDPE Bag)		3.05	3.44	3.75	4.18
P_4 (60 µ LDPE Bag)		3.02	3.45	3.78	4.53
P_5 (80 µ LDPE Bag)		3.06	3.47	3.76	4.21
SEm±		0.01	0.02	0.02	0.02
CD (P=0.05)		0.04	0.05	0.05	0.05
Storage temperature (ºC)					
T_1 (Ambient Temp 10ºC□ 32.5ºC)		3.29	3.64	-	-
T_2 (12ºC)		3.18	3.58	3.89	4.21
T_3 (6ºC)		2.86	3.51	3.90	4.37
SEm±		0.01	0.01	0.01	0.02
CD (P=0.05)		0.03	0.04	NS	0.05
Packaging material X Storage temperature					
T_1	P_1T_1	3.59	3.95	-	-
T_2	P_2T_1	3.32	3.78	-	-
T_3	P_3T_1	3.20	3.45	-	-
T_4	P_4T_1	3.14	3.56	-	-
T_5	P_5T_1	3.21	3.48	-	-
T_6	P_1T_2	3.32	3.93	4.26	4.30
T_7	P_2T_2	3.20	3.56	3.93	4.20
T_8	P_3T_2	3.14	3.47	3.74	3.96
T_9	P_4T_2	3.11	3.42	3.76	4.60
T_{10}	P_5T_2	3.12	3.50	3.75	4.01
T_{11}	P_1T_3	2.97	3.86	4.24	4.31
T_{12}	P_2T_3	2.86	3.51	3.96	4.32
T_{13}	P_3T_3	2.81	3.39	3.76	4.39
T_{14}	P_4T_3	2.80	3.38	3.79	4.45
T_{15}	P_5T_3	2.84	3.42	3.77	4.40
SEm±		0.02	0.03	0.03	0.03
CD (P=0.05)		0.07	0.09	0.08	0.09

'—' denotes no fruits under treatments at 15 and 20 days of storage.

Note: Initial value of fresh tomato fruits = 2.34 mg $100g^{-1}$

Table 4.12 Effect of packaging material and storage temperature on decay (%) of tomato fruit during storage

Treatment		Storage day			
		5	10	15	20
Packaging material					
P_1 (Control)		3.69	8.82	12.16	16.72
P_2 (20 µLDPE Bag)		3.56	8.01	11.76	15.99
P_3 (40 µ LDPE Bag)		3.18	7.84	10.80	15.46
P_4 (60 µ LDPE Bag)		1.40	4.80	7.63	13.44
P_5 (80 µLDPE Bag)		2.93	6.86	9.08	14.68
SEm±		0.01	0.03	0.062	0.091
CD (P=0.05)		0.04	0.10	0.182	0.27
Storage temperature (ºC)					
T_1(Ambien Temp 10ºC□ 32.5ºC)		3.96	11.89	-	-
T_2 (12ºC)		2.75	5.16	9.17	13.65
T_3 (6ºC)		2.14	4.74	11.40	16.87
SEm±		0.01	0.03	0.06	0.09
CD (P=0.05)		0.03	0.08	0.18	0.27
Packaging material X Storage temperature					
T_1	P_1T_1	5.02	15.03	-	-
T_2	P_2T_1	4.82	13.05	-	-
T_3	P_3T_1	4.61	12.09	-	-
T_4	P_4T_1	1.92	8.14	-	-
T_5	P_5T_1	3.45	11.16	-	-
T_6	P_1T_2	3.12	6.23	11.17	15.26
T_7	P_2T_2	3.06	5.96	10.96	14.41
T_8	P_3T_2	2.98	5.81	9.56	14.02
T_9	P_4T_2	1.26	3.24	6.42	11.21
T_{10}	P_5T_2	3.33	4.56	7.73	13.34
T_{11}	P_1T_3	2.92	5.21	13.14	18.18
T_{12}	P_2T_3	2.81	5.01	12.56	17.57
T_{13}	P_3T_3	1.96	5.63	12.04	16.89
T_{14}	P_4T_3	1.02	3.02	8.83	15.67
T_{15}	P_5T_3	2.01	4.85	10.42	16.02
SEm±		0.02	0.06	0.03	0.04
CD (P=0.05)		0.07	0.17	0.09	0.13

'—' denotes no fruits under treatments at 15 and 20 days of storage.

Note: Initial value of fresh tomato fruits = 0%

Table 4.13.1 Effect of packaging material and storage temperature on color L* of tomato fruit during storage

Treatment		Storage day			
		5	10	15	20
Packaging material					
P_1 (Control)		36.80	40.04	42.50	45.69
P_2 (20 µ LDPE Bag)		33.94	36.82	39.09	42.29
P_3 (40 µ LDPE Bag)		31.21	33.41	35.35	38.55
P_4 (60 µ LDPE Bag)		27.36	28.97	31.92	33.80
P_5 (80 µ LDPE Bag)		29.53	30.78	33.81	36.46
SEm±		0.14	0.15	0.45	0.50
CD (P=0.05)		0.41	0.44	1.33	1.50
Storage temperature (ºC)					
T_1 (Ambient Temp 10ºC□ 32.5ºC)		33.34	36.71	-	-
T_2 (12ºC)		31.54	33.04	35.13	37.28
T_3 (6ºC)		30.44	32.25	37.93	41.43
SEm±		0.11	0.12	0.45	0.50
CD (P=0.05)		0.32	0.34	1.33	1.46
Packaging material X Storage temperature					
T_1	P_1T_1	38.37	44.35	-	-
T_2	P_2T_1	35.51	40.40	-	-
T_3	P_3T_1	32.78	35.65	-	-
T_4	P_4T_1	28.93	30.01	-	-
T_5	P_5T_1	31.10	33.15	-	-
T_6	P_1T_2	36.57	38.24	41.86	44.92
T_7	P_2T_2	33.71	35.38	37.91	40.97
T_8	P_3T_2	30.98	32.65	33.16	36.22
T_9	P_4T_2	27.13	28.80	30.14	30.58
T_{10}	P_5T_2	29.30	30.14	32.58	33.72
T_{11}	P_1T_3	35.47	37.53	43.13	46.46
T_{12}	P_2T_3	32.61	34.67	40.27	43.60
T_{13}	P_3T_3	29.88	31.94	37.54	40.87
T_{14}	P_4T_3	26.03	28.09	33.69	37.02
T_{15}	P_5T_3	28.20	29.04	35.03	39.19
SEm±		0.25	0.26	0.21	0.23
CD (P=0.05)		0.72	0.76	0.64	0.70

'—' denotes no fruits under treatments at 15 and 20 days of storage.

Note: Initial value of fresh tomato fruits = 22.35

Table 4.13.2 Effect of packaging material and storage temperature on colour a* of tomato fruit during storage

Treatment		Storage day			
		5	**10**	**15**	**20**
Packaging material					
P_1 (Control)		11.92	14.90	17.85	19.78
P_2 (20 µ LDPE Bag)		11.07	14.27	15.77	16.51
P_3 (40 µ LDPE Bag)		9.95	13.00	14.69	16.38
P_4 (60 µ LDPE Bag)		9.15	10.30	12.66	13.43
P_5 (80 µ LDPE Bag)		9.37	11.74	13.95	14.61
SEm±		0.09	0.06	0.09	0.10
CD (P=0.05)		0.27	0.17	0.26	0.30
Storage temperature (ºC)					
T_1 (Ambient Temp 10ºC□ 32.5ºC)		11.48	14.69	-	-
T_2 (12ºC)		9.95	12.54	14.56	15.96
T_3 (6ºC)		9.45	11.30	15.40	16.32
SEm±		0.07	0.04	0.09	0.10
CD (P=0.05)		0.21	0.13	0.26	0.28
Packaging material X Storage temperature					
T_1	P_1T_1	13.65	18.67	-	-
T_2	P_2T_1	12.55	15.12	-	-
T_3	P_3T_1	11.12	14.12	-	-
T_4	P_4T_1	9.89	12.24	-	-
T_5	P_5T_1	10.20	13.31	-	-
T_6	P_1T_2	11.23	13.56	17.58	19.74
T_7	P_2T_2	10.89	14.81	15.13	16.45
T_8	P_3T_2	9.86	13.41	14.26	16.13
T_9	P_4T_2	8.76	9.78	12.42	13.41
T_{10}	P_5T_2	9.02	11.12	13.41	14.06
T_{11}	P_1T_3	10.89	12.46	18.12	19.82
T_{12}	P_2T_3	9.78	12.89	16.41	16.56
T_{13}	P_3T_3	8.87	11.46	15.12	16.62
T_{14}	P_4T_3	8.81	8.89	12.89	13.45
T_{15}	P_5T_3	8.88	10.79	14.48	15.15
SEm±		0.16	0.10	0.03	0.03
CD (P=0.05)		0.47	0.29	0.12	0.14

'—' denotes no fruits under treatments at 15 and 20 days of storage.

Note: Initial value of fresh tomato fruits = 8.17

Table 4.13.3 Effect of packaging material and storage temperature on color b* of tomato fruit during storage

Treatment		Storage day			
		5	10	15	20
Packaging material					
P_1 (Control)		20.77	25.30	29.92	37.48
P_2 (20 µ LDPE Bag)		19.49	24.07	27.92	35.96
P_3 (40 µ LDPE Bag)		18.76	22.81	24.94	34.06
P_4 (60 µ LDPE Bag)		15.71	17.71	21.82	28.90
P_5 (80 µ LDPE Bag)		18.04	20.17	24.13	31.28
SEm±		0.08	0.10	0.151	0.200
CD (P=0.05)		0.24	0.28	0.45	0.59
Storage temperature (ºC)					
T_1 (Ambient Temp 10ºC□ 32.5ºC)		20.41	24.42	-	-
T_2 (12ºC)		18.47	21.31	25.27	33.28
T_3 (6ºC)		16.77	20.31	26.22	33.78
SEm±		0.06	0.08	0.15	0.20
CD (P=0.05)		0.19	0.22	0.45	0.59
Packaging material X Storage temperature					
T_1	P_1T_1	23.68	27.89	-	-
T_2	P_2T_1	21.13	25.43	-	-
T_3	P_3T_1	20.08	24.32	-	-
T_4	P_4T_1	17.76	21.31	-	-
T_5	P_5T_1	19.42	23.14	-	-
T_6	P_1T_2	20.17	24.12	29.41	38.46
T_7	P_2T_2	19.46	23.99	27.69	35.78
T_8	P_3T_2	19.13	22.17	24.30	33.24
T_9	P_4T_2	15.13	16.42	21.47	28.62
T_{10}	P_5T_2	18.45	19.83	23.48	30.32
T_{11}	P_1T_3	18.46	23.89	30.42	36.49
T_{12}	P_2T_3	17.87	22.78	28.15	36.13
T_{13}	P_3T_3	17.06	21.93	25.57	34.87
T_{14}	P_4T_3	14.23	15.41	22.17	29.17
T_{15}	P_5T_3	16.25	17.54	24.78	32.23
SEm±		0.14	0.17	0.07	0.09
CD (P=0.05)		0.42	0.49	0.21	0.28

'—' denotes no fruits under treatments at 15 and 20 days of storage.

Note: Initial value of fresh tomato fruits = 14,47

Table 4.14 Effect of packaging material and storage temperature on over all organoleptic score of tomato fruit during storage

Treatment		Storage day			
		5	10	15	20
Packaging material					
P_1 (Control)		5.93	5.31	6.01	4.96
P_2 (20 µ LDPE Bag)		5.91	5.54	6.01	5.12
P_3 (40 µ LDPE Bag)		5.89	5.57	6.15	5.23
P_4 (60 µ LDPE Bag)		5.75	5.64	6.54	5.65
P_5 (80 µ LDPE Bag)		5.84	5.57	6.20	5.30
SEm±		0.03	0.03	0.03	0.03
CD (P=0.05)		0.08	0.07	0.09	0.08
Storage temperature (ºC)					
T_1 (Ambient Temp 10ºC□ 32.5ºC)		6.17	4.92	-	-
T_2 (12ºC)		5.79	5.90	6.44	5.40
T_3 (6ºC)		5.64	5.76	5.92	5.10
SEm±		0.02	0.02	0.02	0.02
CD (P=0.05)		0.05	0.05	0.06	0.05
Packaging material X Storage temperature					
T_1	P_1T_1	6.28	4.12	-	-
T_2	P_2T_1	6.17	4.89	-	-
T_3	P_3T_1	6.25	5.01	-	-
T_4	P_4T_1	6.08	5.34	-	-
T_5	P_5T_1	6.25	5.23	-	-
T_6	P_1T_2	5.92	5.98	6.03	5.02
T_7	P_2T_2	5.88	5.92	6.23	5.25
T_8	P_3T_2	5.78	5.96	6.42	5.42
T_9	P_4T_2	5.66	5.88	7.05	5.84
T_{10}	P_5T_2	5.72	5.76	6.45	5.46
T_{11}	P_1T_3	5.78	5.82	5.98	4.89
T_{12}	P_2T_3	5.69	5.81	5.78	4.98
T_{13}	P_3T_3	5.64	5.74	5.88	5.03
T_{14}	P_4T_3	5.52	5.69	6.03	5.45
T_{15}	P_5T_3	5.56	5.72	5.95	5.13
SEm±		0.05	0.05	0.05	0.04
CD (P=0.05)		0.13	0.13	0.15	0.13

'—' denotes no fruits under treatments at 15 and 20 days of storage.

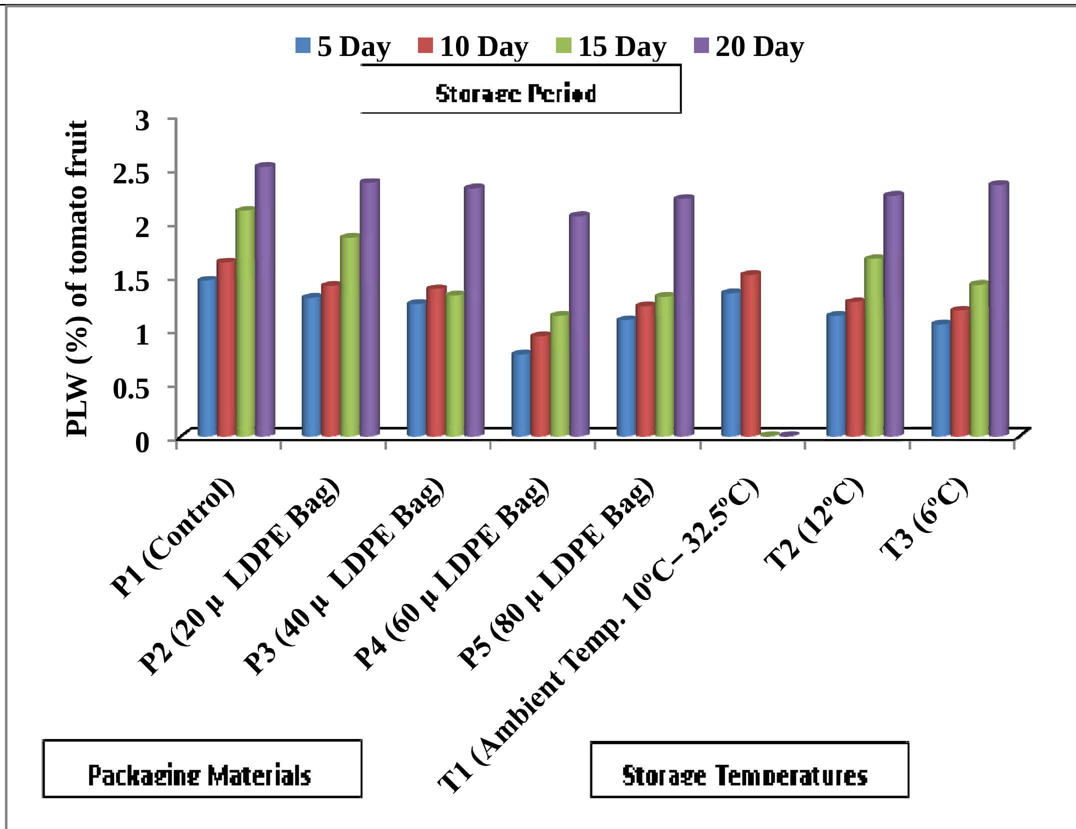
Note: Initial value of fresh tomato fruits = 5

Table 4.15 Effect of packaging material and storage temperature on chilling injury (out of 5 marks) of tomato fruit during storage

Treatment		Storage day			
		5	10	15	20
Packaging material					
P_1 (Control)		0.00	0.00	0.24	1.91
P_2 (20 µ LDPE Bag)		0.00	0.00	0.17	1.85
P_3 (40 µ LDPE Bag)		0.00	0.00	0.14	1.71
P_4 (60 µ LDPE Bag)		0.00	0.00	0.06	0.98
P_5 (80 µ LDPE Bag)		0.00	0.00	0.13	1.49
SEm±		0.000	0.000	0.001	0.008
CD (P=0.05)		0.000	0.000	0.002	0.025
Storage temperature (ºC)					
T_1 (Ambient Temp 10ºC□ 32.5ºC)		0.00	0.00	-	-
T_2 (12ºC)		0.00	0.00	0.11	1.10
T_3 (6ºC)		0.00	0.00	0.18	2.07
SEm±		0.000	0.000	0.001	0.005
CD (P=0.05)		0.000	0.000	0.003	0.016
Packaging material X Storage temperature					
T_1	P_1T_1	0.00	0.00	-	-
T_2	P_2T_1	0.00	0.00	-	-
T_3	P_3T_1	0.00	0.00	-	-
T_4	P_4T_1	0.00	0.00	-	-
T_5	P_5T_1	0.00	0.00	-	-
T_6	P_1T_2	0.00	0.00	0.22	1.26
T_7	P_2T_2	0.00	0.00	0.15	1.21
T_8	P_3T_2	0.00	0.00	0.11	1.09
T_9	P_4T_2	0.00	0.00	0.00	0.95
T_{10}	P_5T_2	0.00	0.00	0.09	1.01
T_{11}	P_1T_3	0.00	0.00	0.26	2.56
T_{12}	P_2T_3	0.00	0.00	0.19	2.48
T_{13}	P_3T_3	0.00	0.00	0.17	2.33
T_{14}	P_4T_3	0.00	0.00	0.12	1.01
T_{15}	P_5T_3	0.00	0.00	0.16	1.97
SEm±		0.000	0.000	0.001	0.015
CD (P=0.05)		0.000	0.000	0.004	0.043

'—' denotes no fruits under treatments at 15 and 20 days of storage.

Note: Initial value of fresh tomato fruits = 0



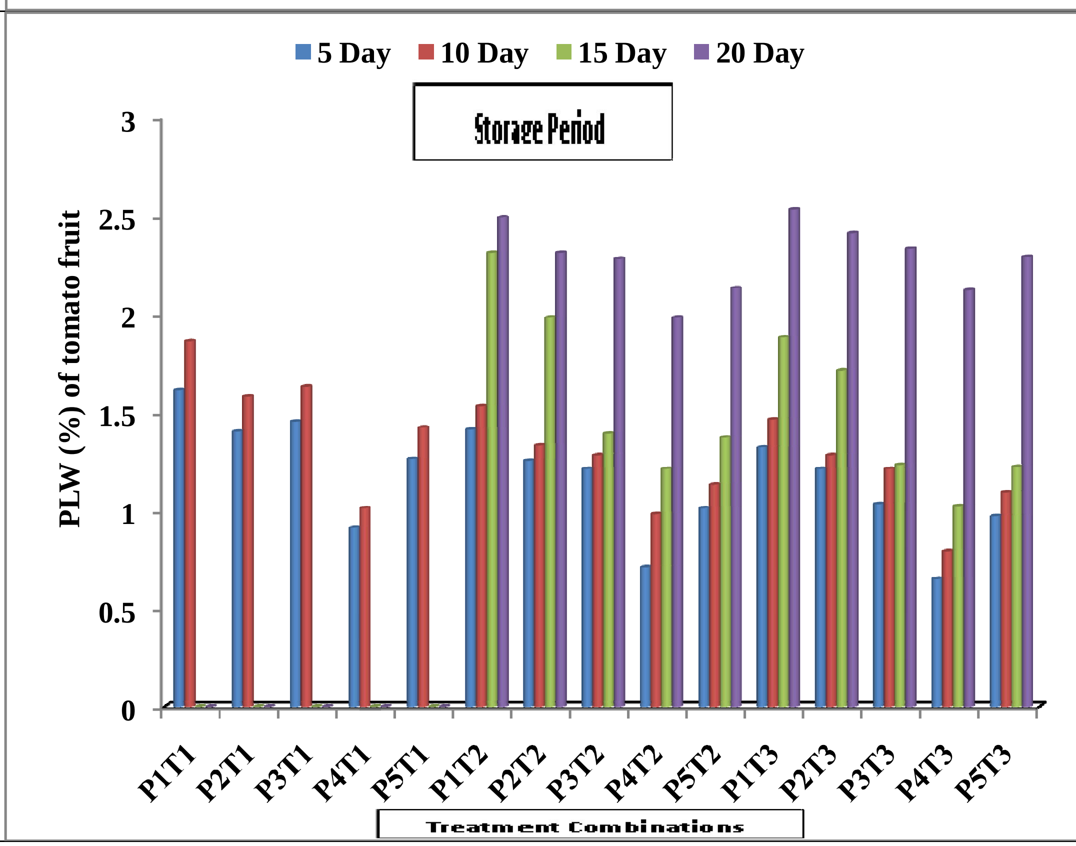
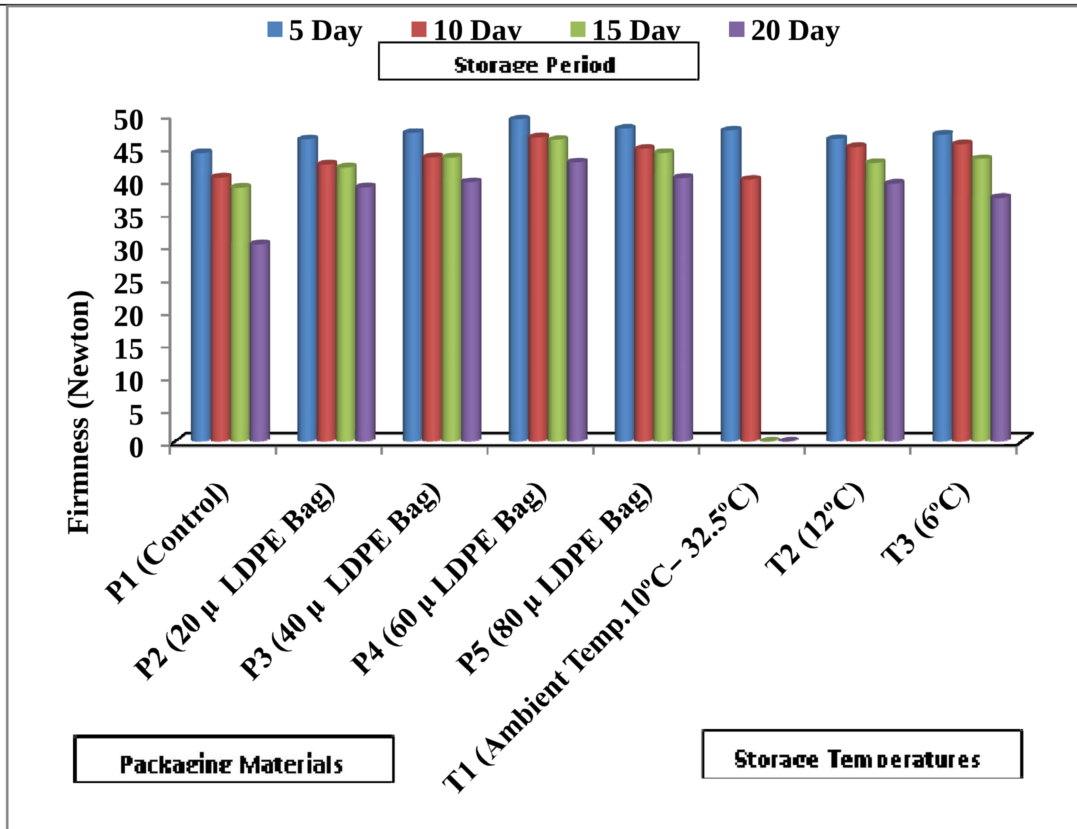


Fig. 4.1. Effect of packaging material, storage temperature and their interaction on PLW (%) of tomato fruits



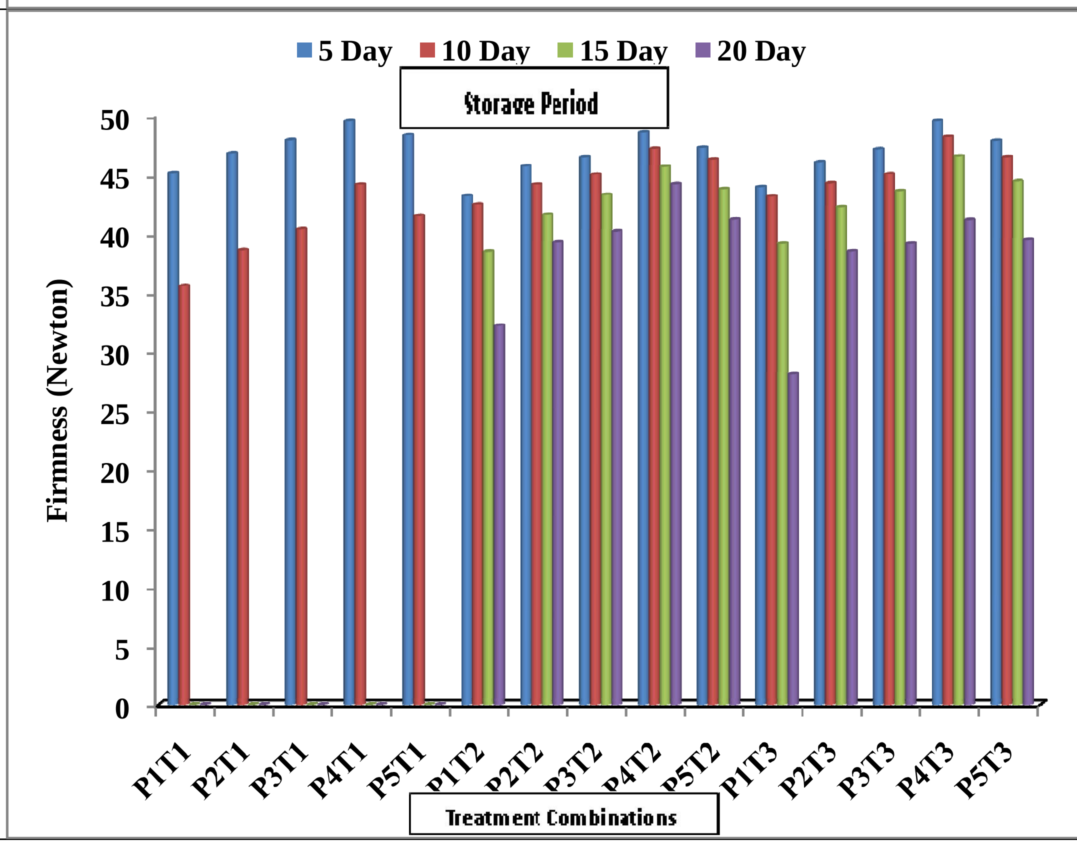
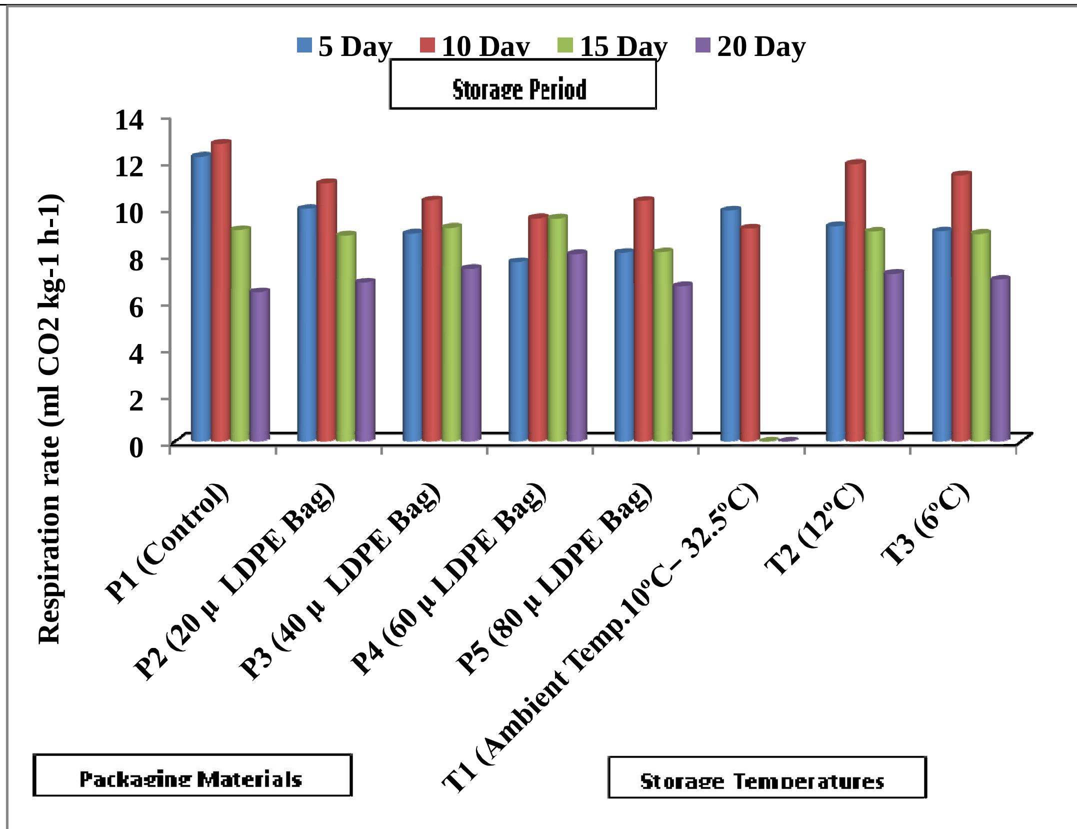


Fig. 4.2 Effect of packaging material, storage temperature and their interaction on firmness of tomato fruits



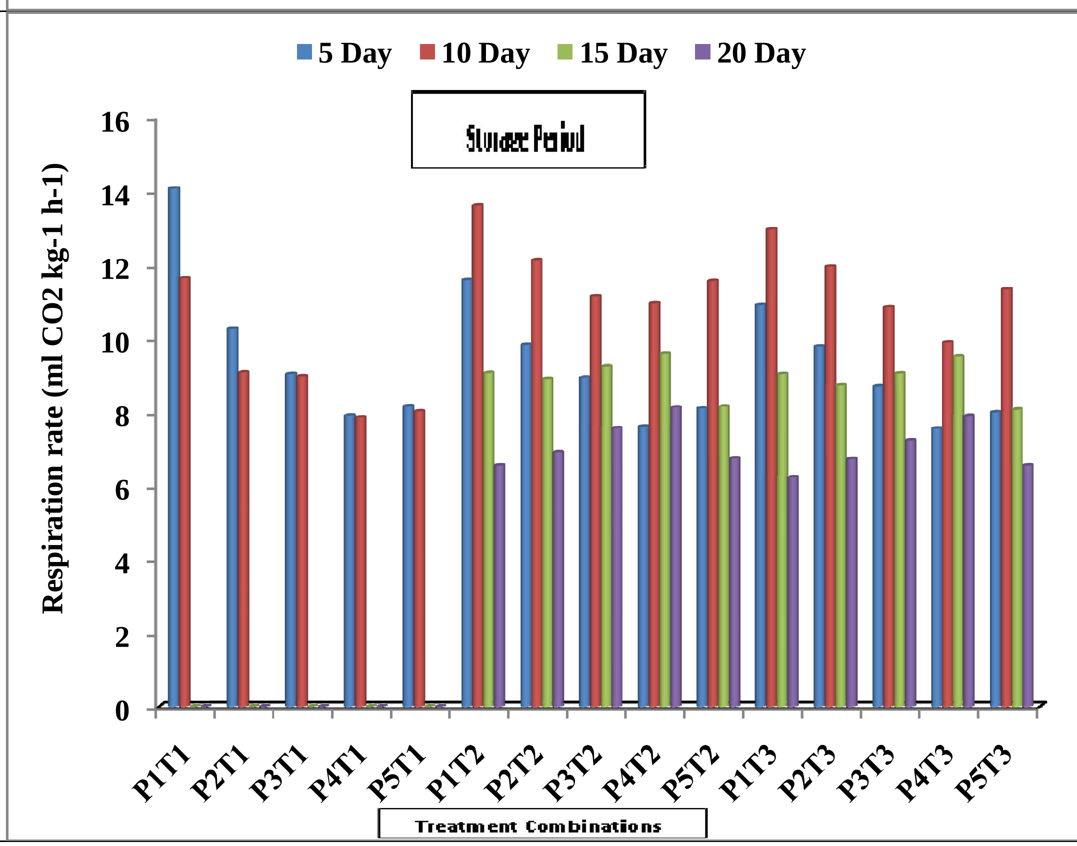
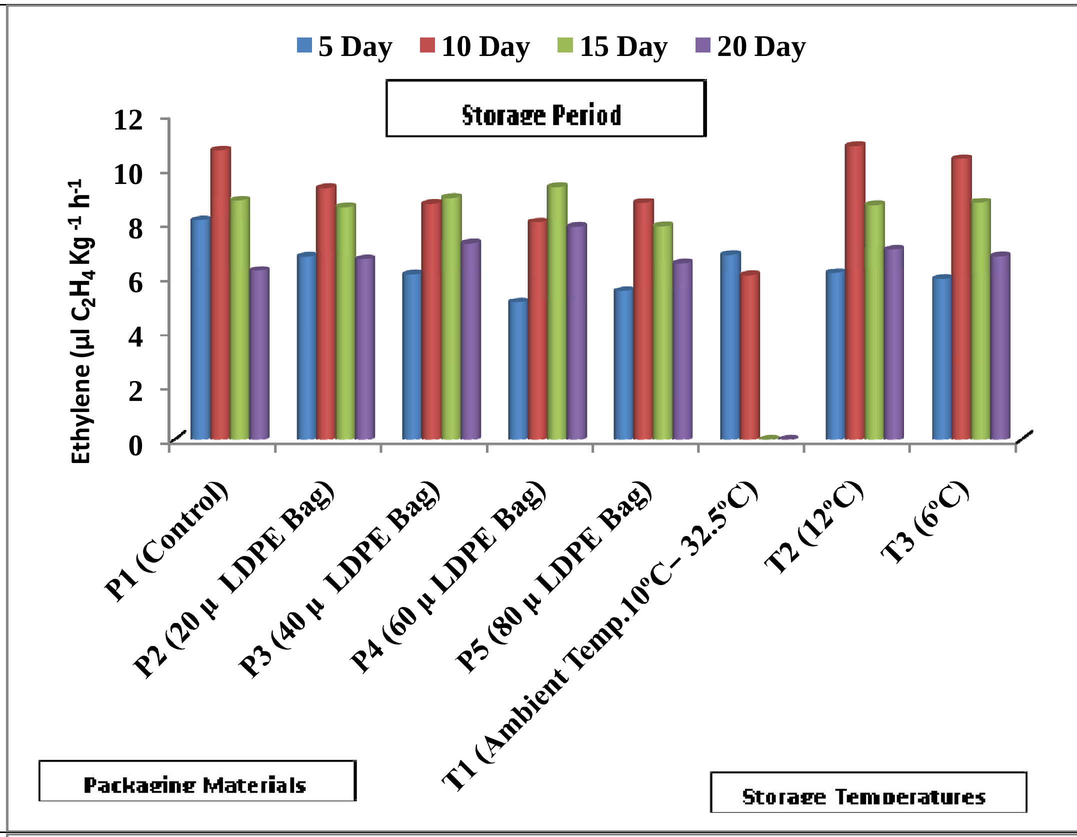


Fig. 4.3 Effect of packaging material, storage temperature and their interaction on respiration rate (ml CO_2 kg^{-1} h^{-1}) of tomato fruits



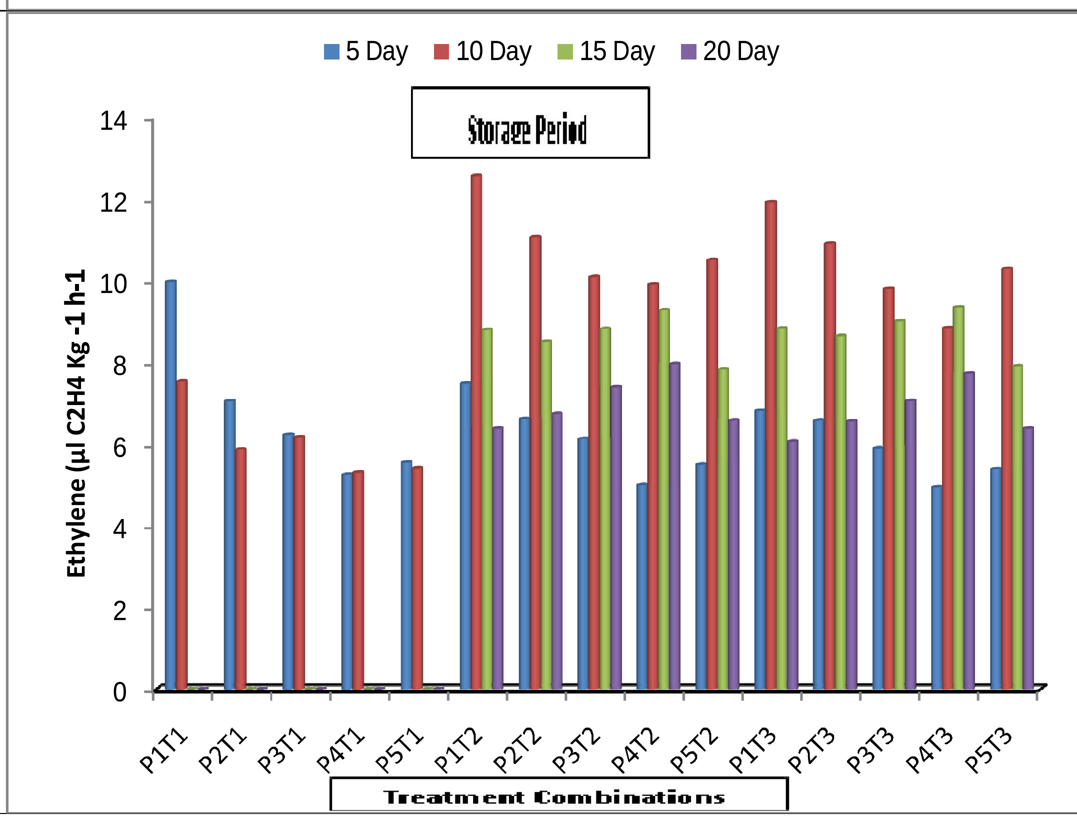
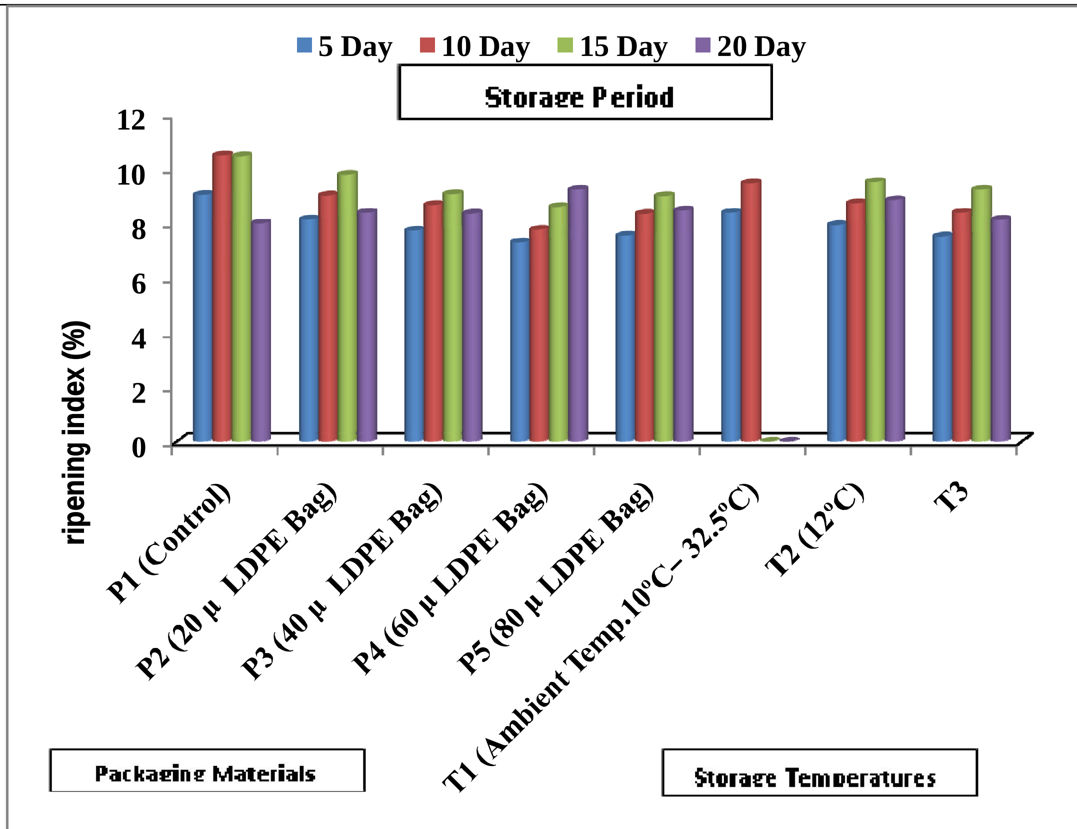


Fig. 4.4. Effect of packaging material, storage temperature and their interaction on Ethylene (µl C_2H_4 Kg $^{-1}$ h^{-1})of tomato fruits



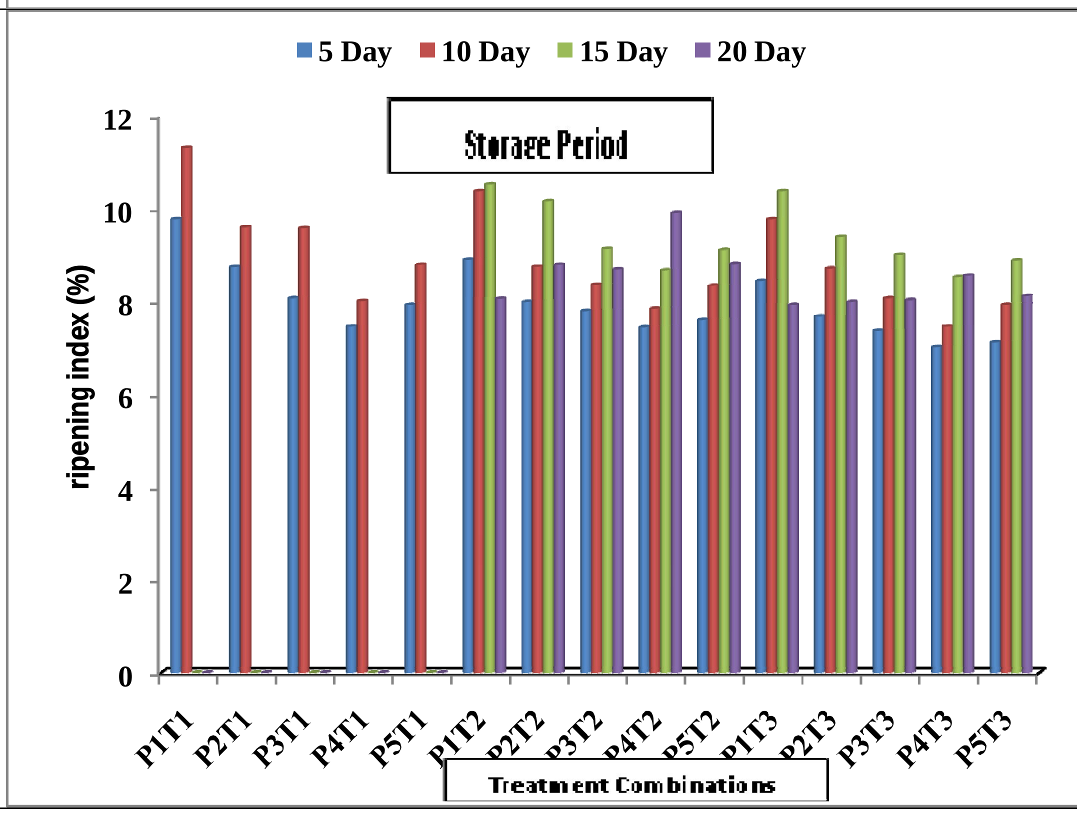


Fig. 4.5 Effect of packaging material, storage temperature and their interaction on ripening index(%) of tomato fruits

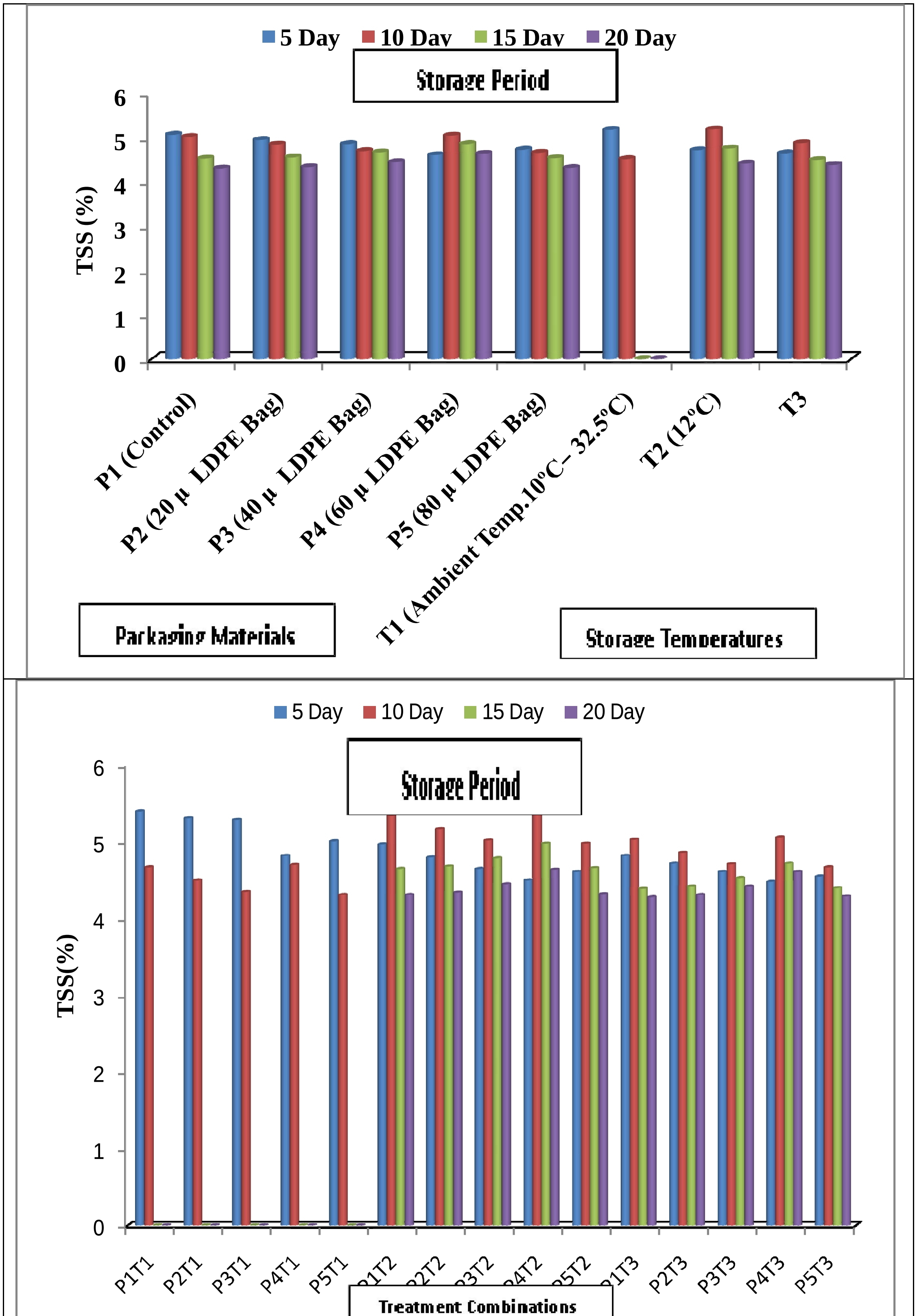
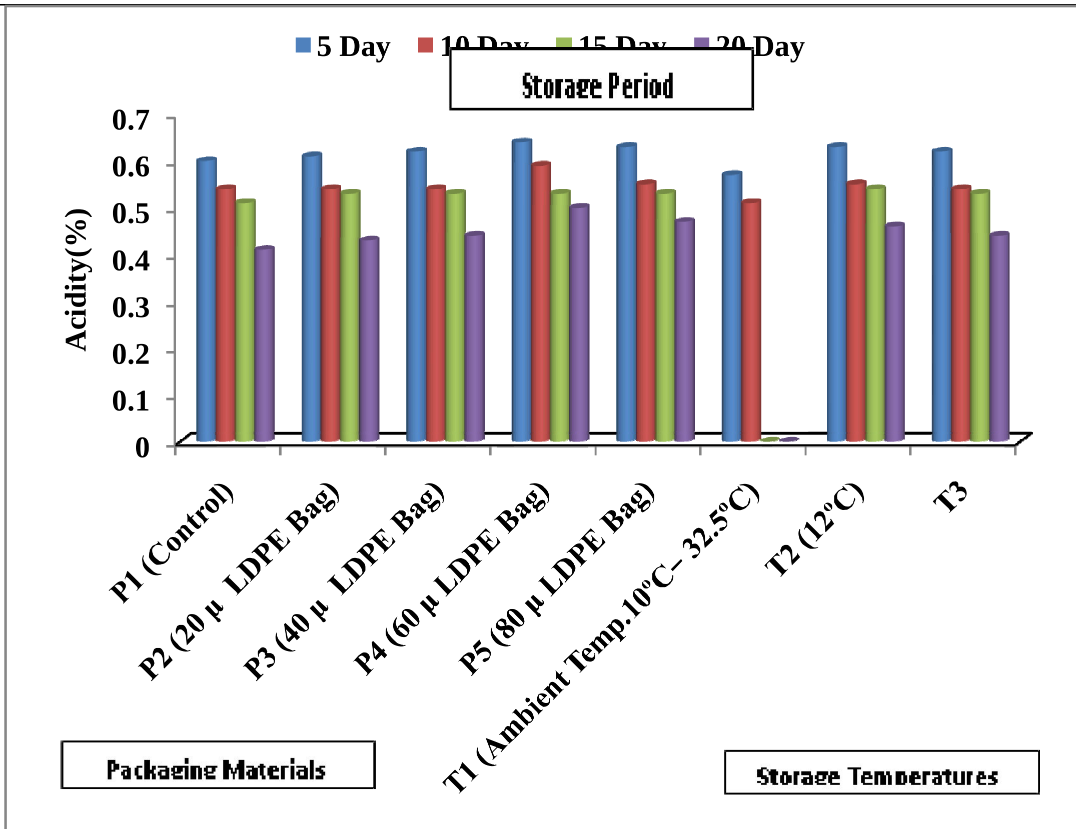


Fig. 4.6 Effect of packaging material, storage temperature and their interaction on TSS(%) of tomato fruits



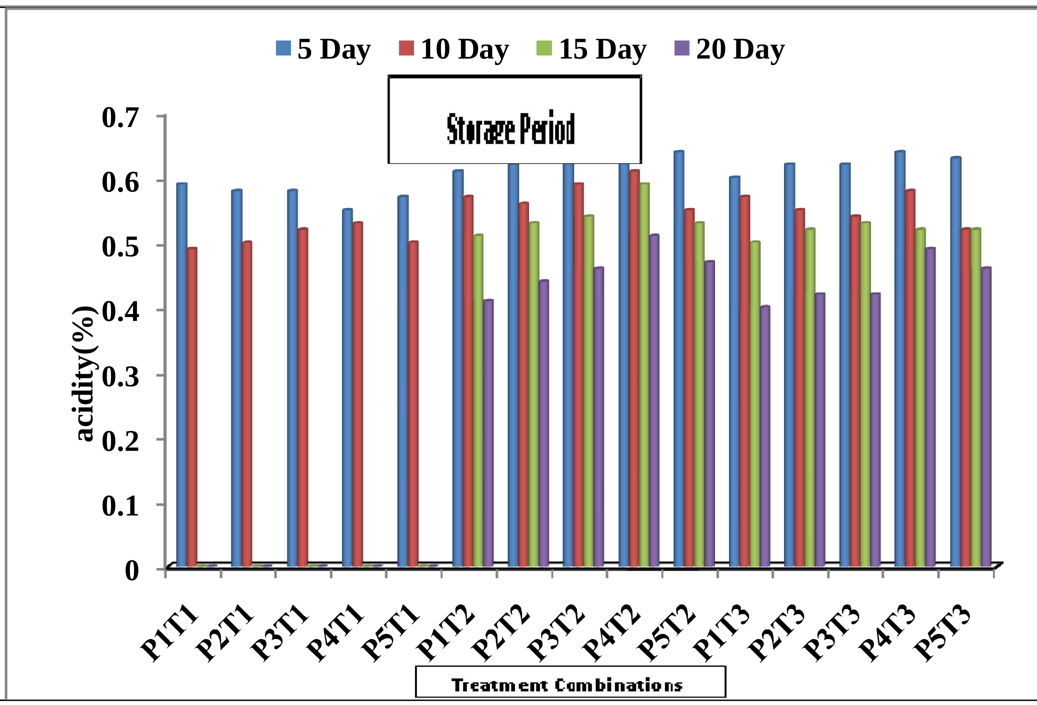
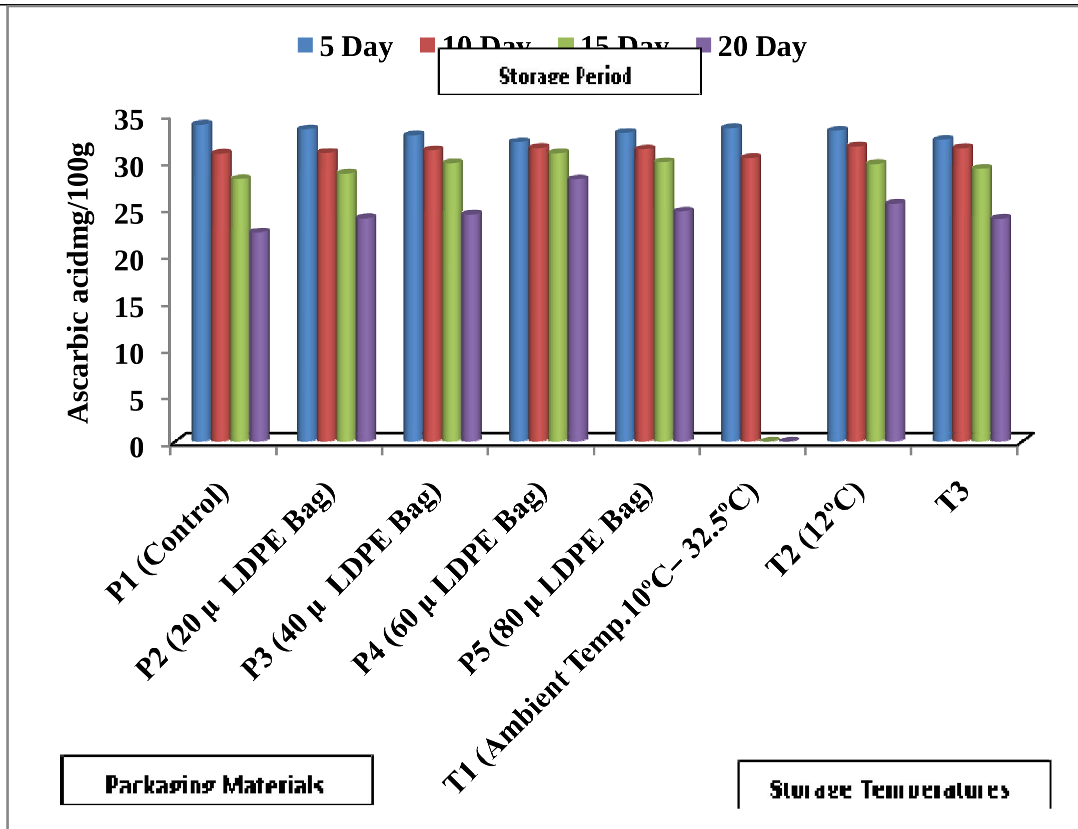


Fig. 4.7 Effect of packaging material, storage temperature and their interaction on Acidity(%) of tomato fruits



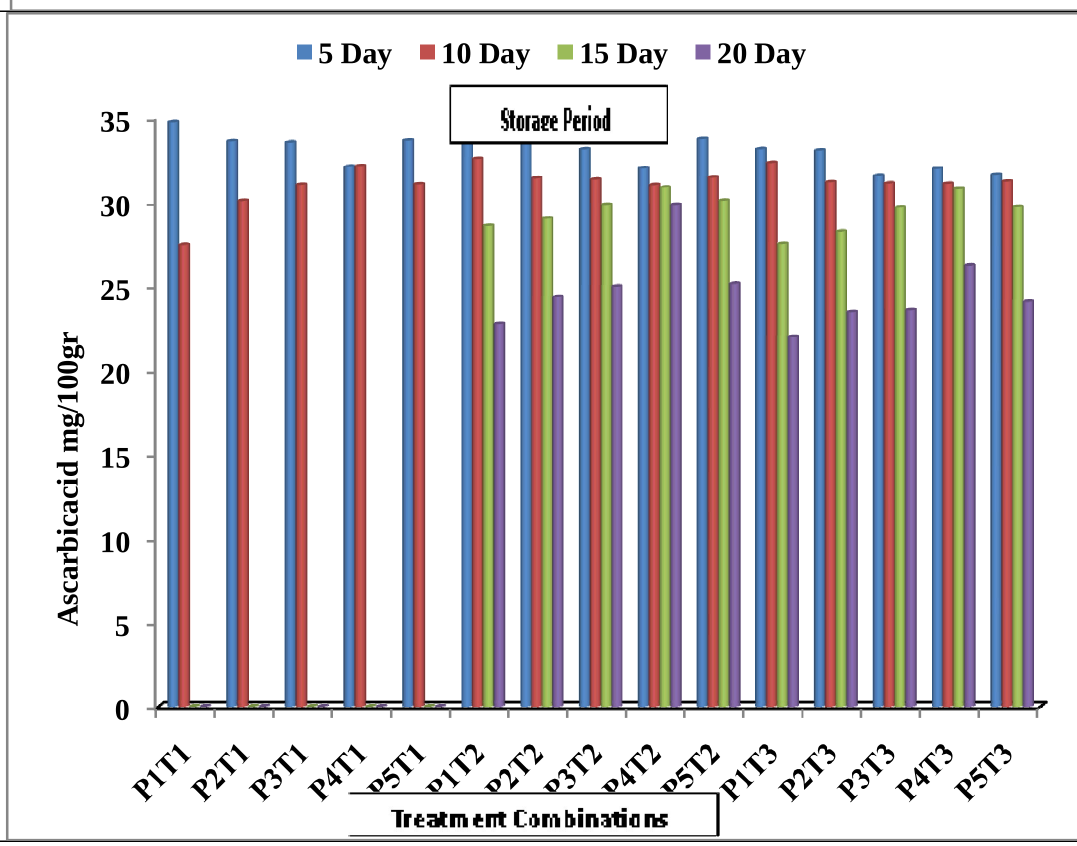
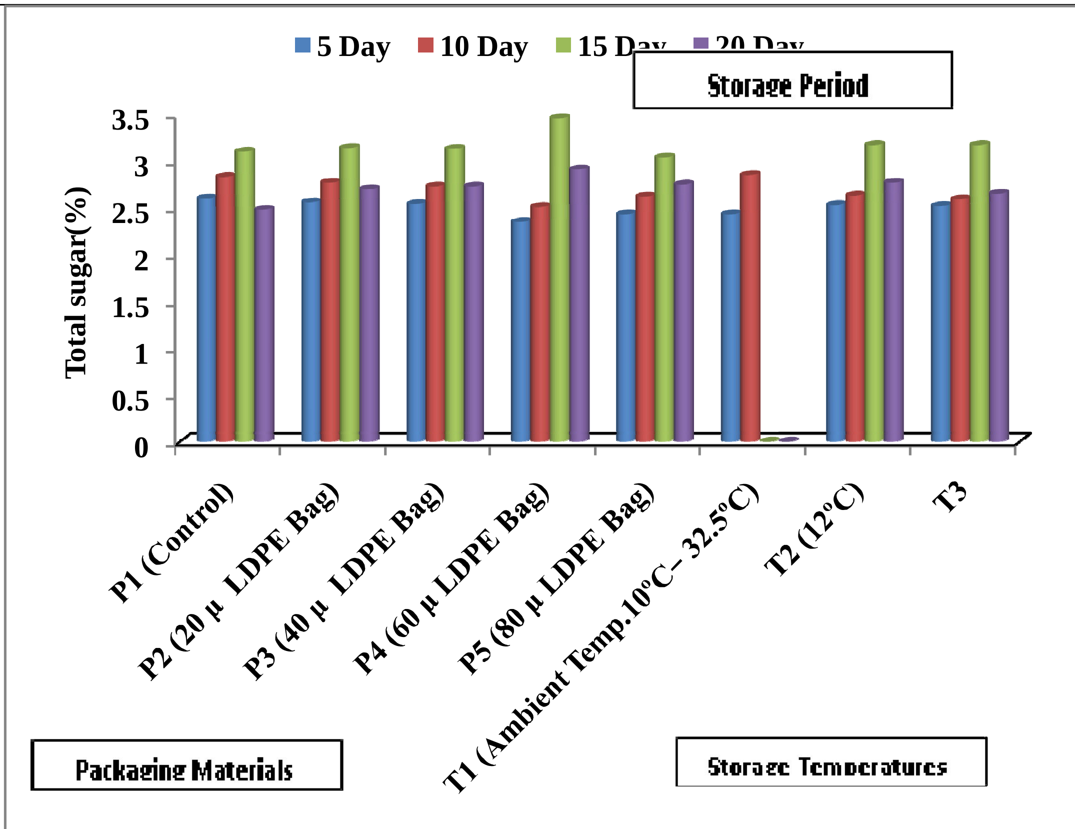


Fig. 4.8 Effect of packaging material, storage temperature and their interaction on Ascarbic acid mg/100g of tomato fruits



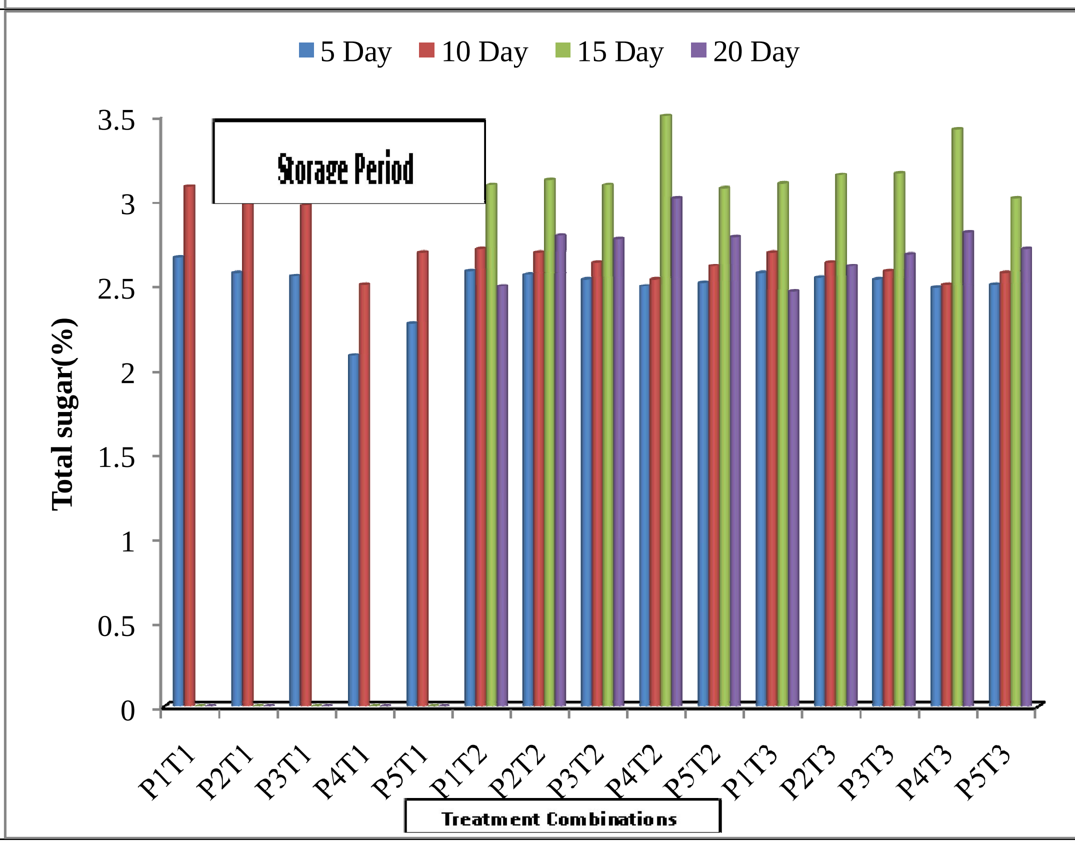


Fig. 4.9 Effect of packaging material, storage temperature and their interaction on Total sugar(%) of tomato fruits

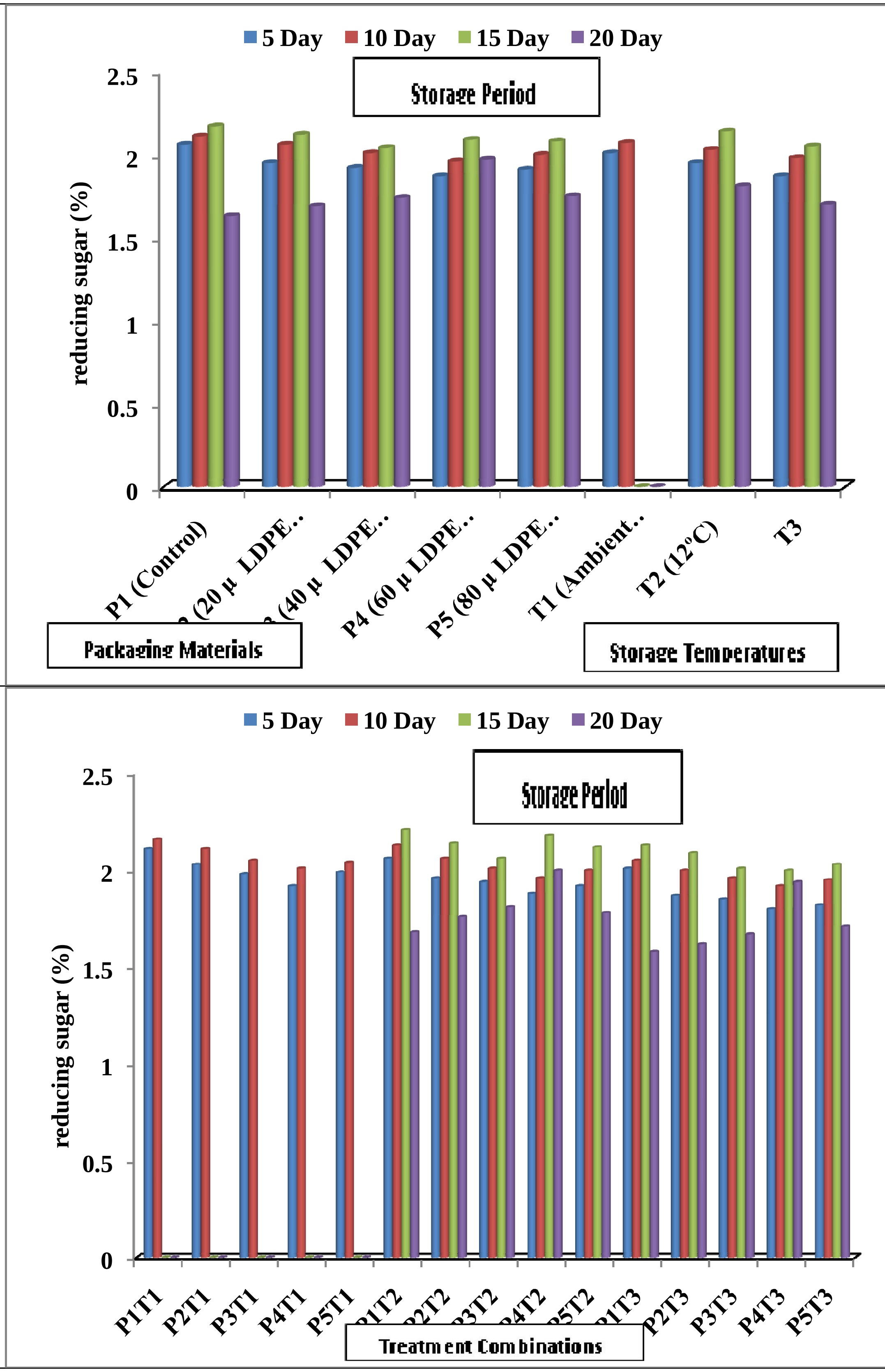


Fig. 4.10 Effect of packaging material, storage temperature and their interaction on Reducing sugar(%) of tomato fruits

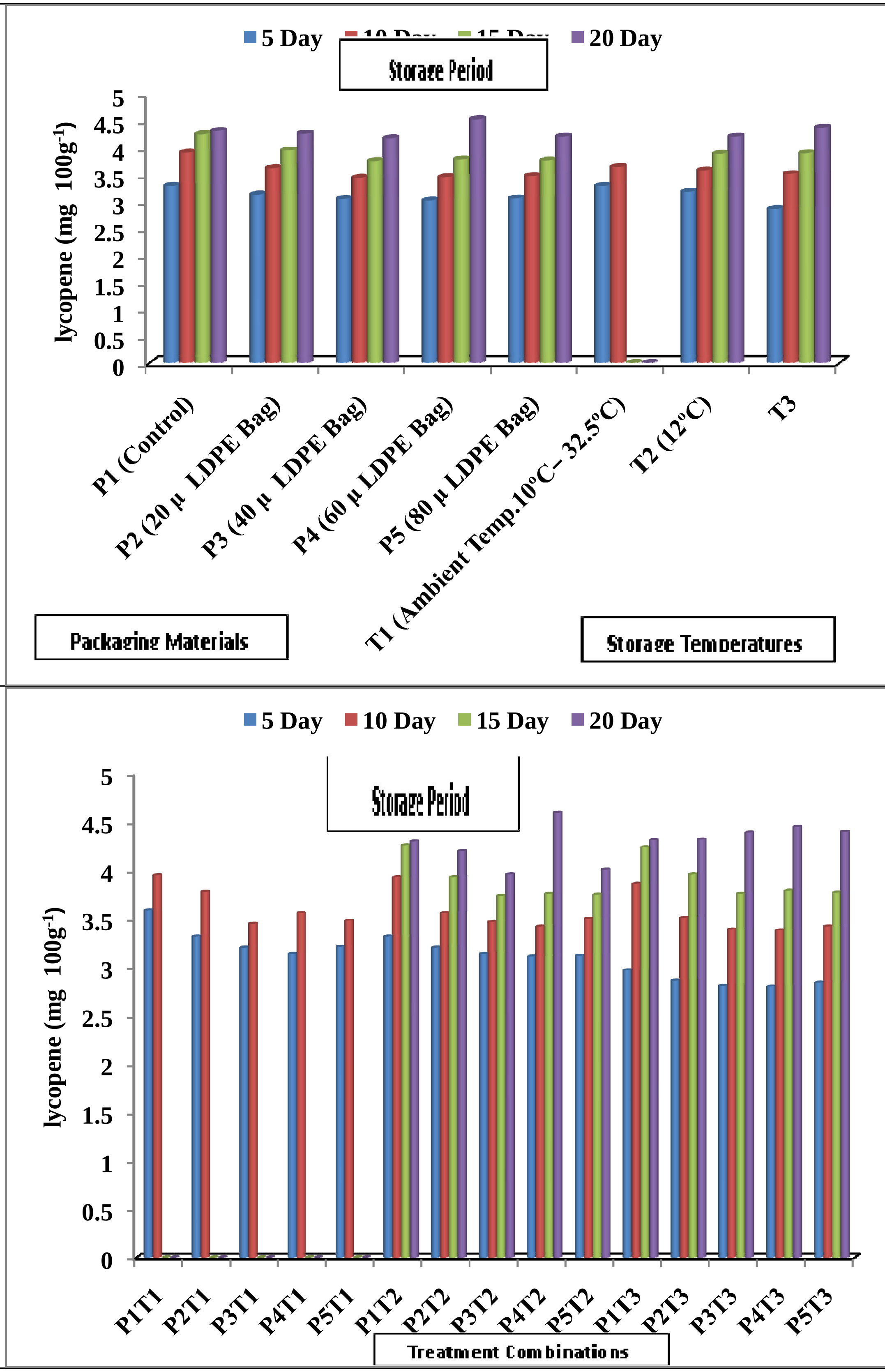


Fig. 4.11 Effect of packaging material, storage temperature and their interaction on lycopene (mg 100g^{-1}) of tomato fruits

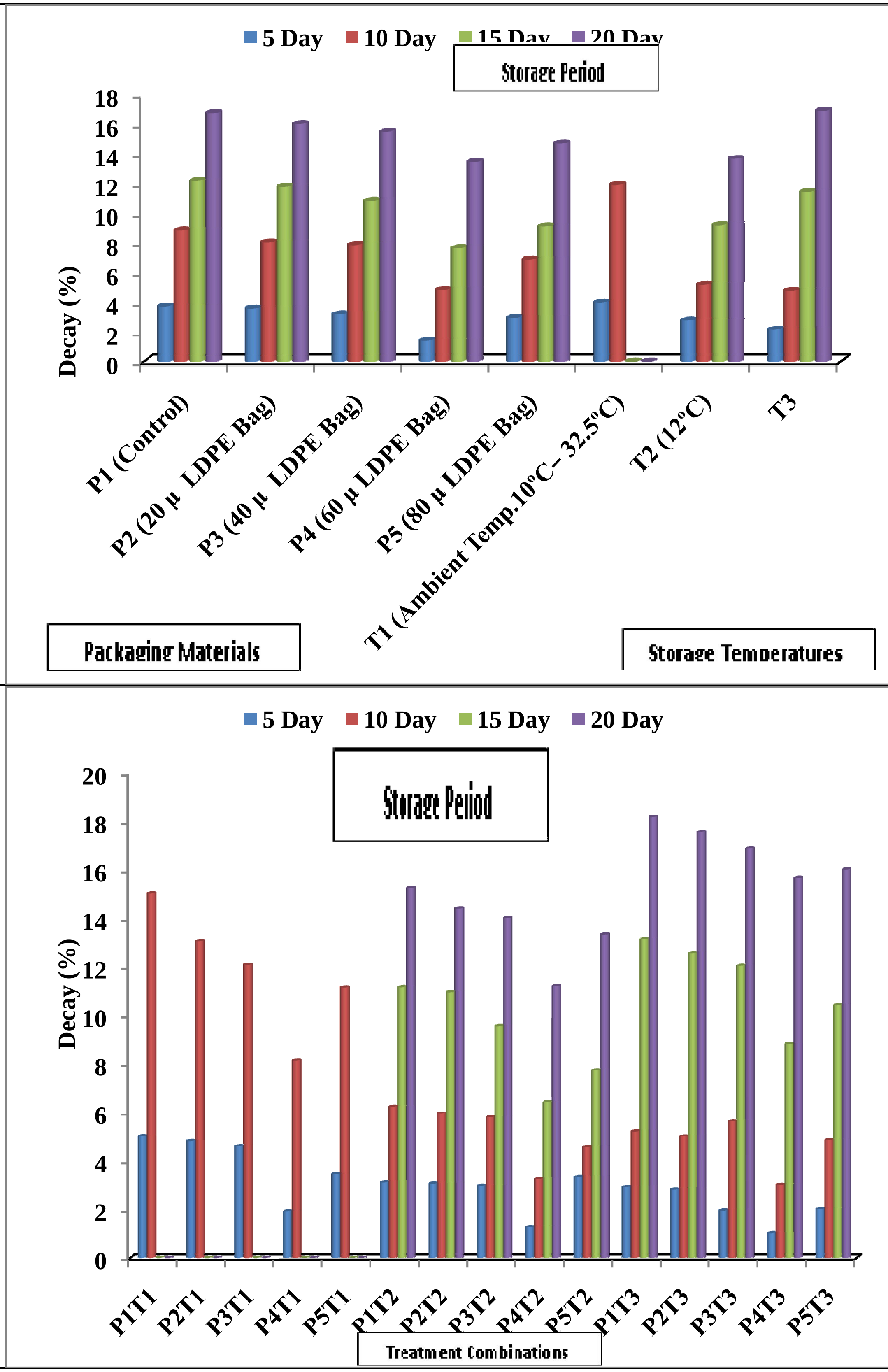
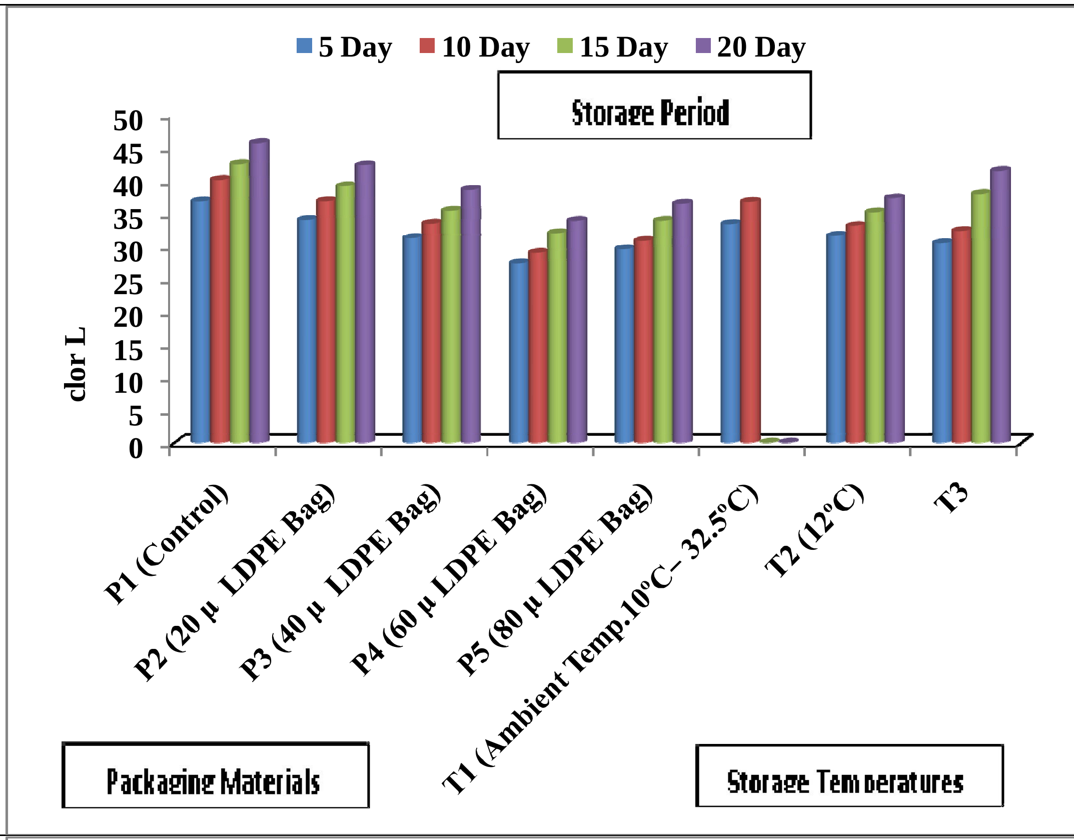


Fig. 4.12 Effect of packaging material, storage temperature and their interaction on Decay (%) of tomato fruits



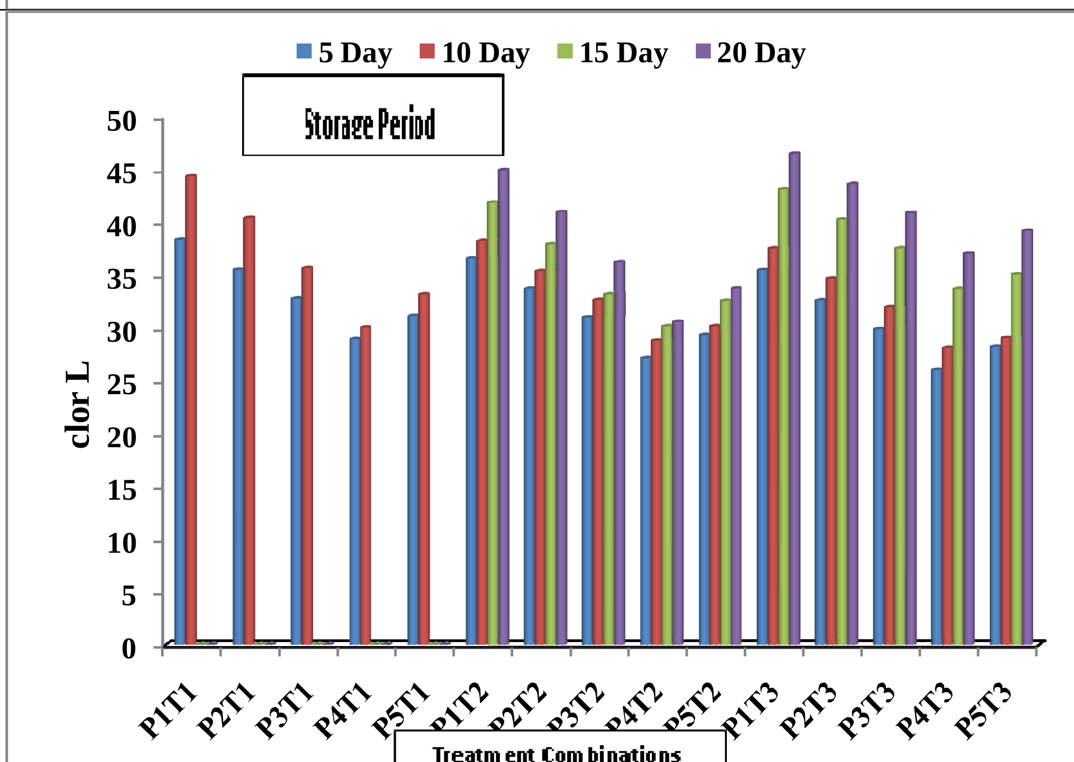
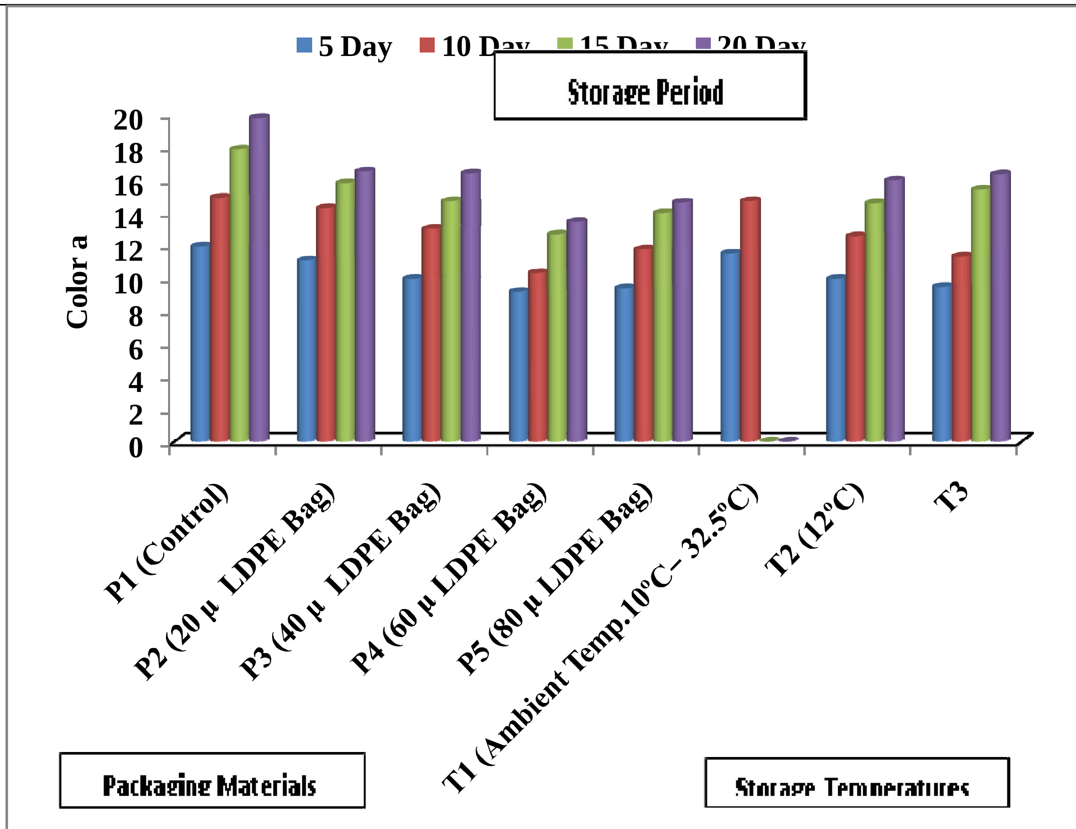


Fig. 4.13.1 Effect of packaging material, storage temperature and their interaction on Color L of tomato fruits



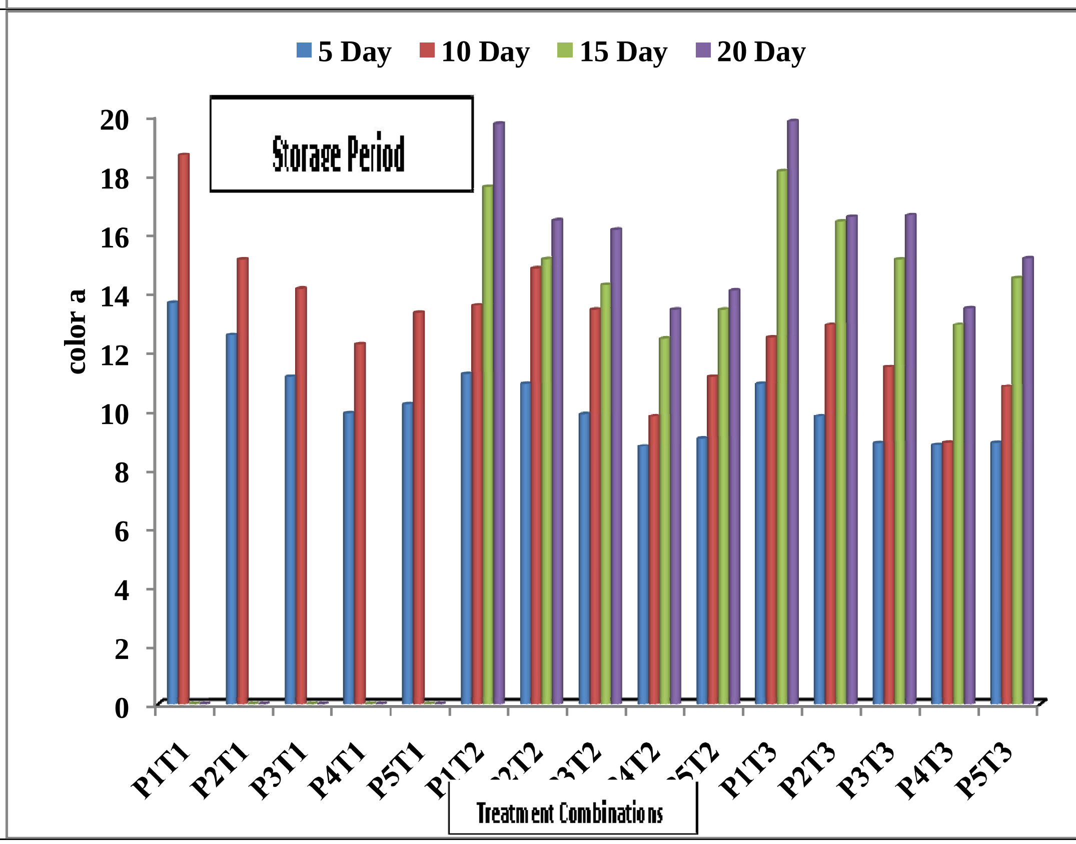
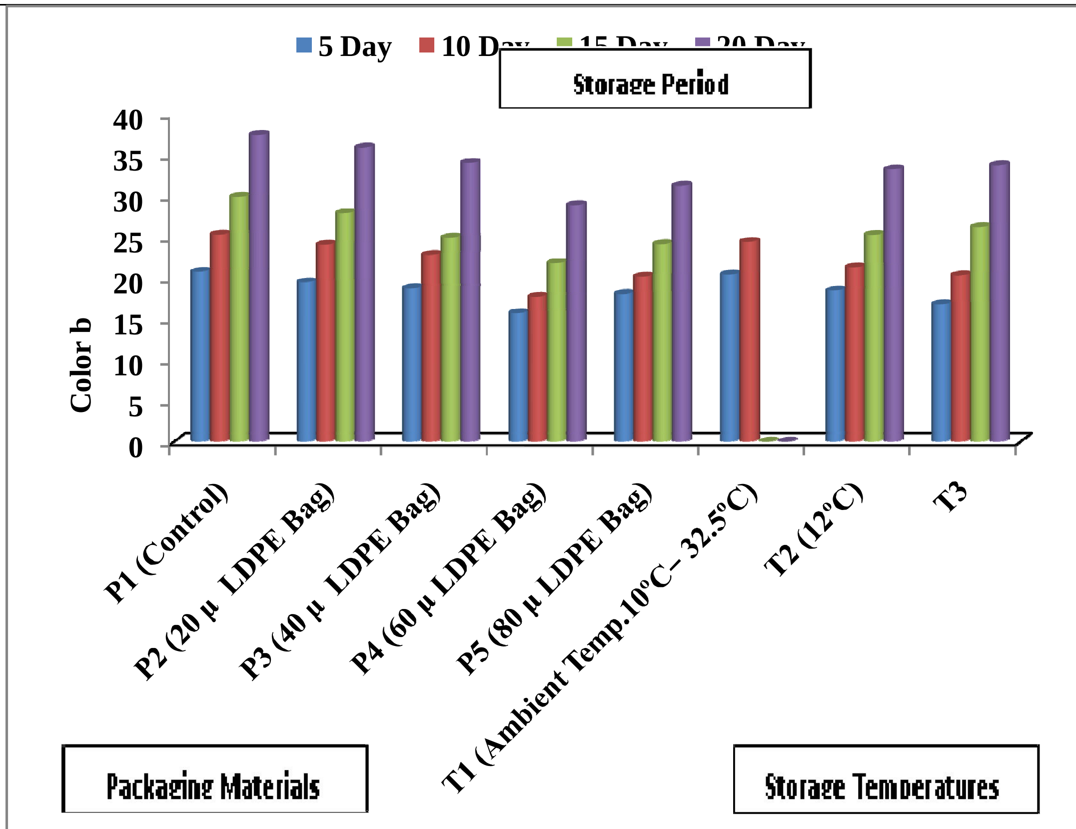


Fig. 4.13.2 Effect of packaging material, storage temperature and their interaction on Colo a of tomato fruits



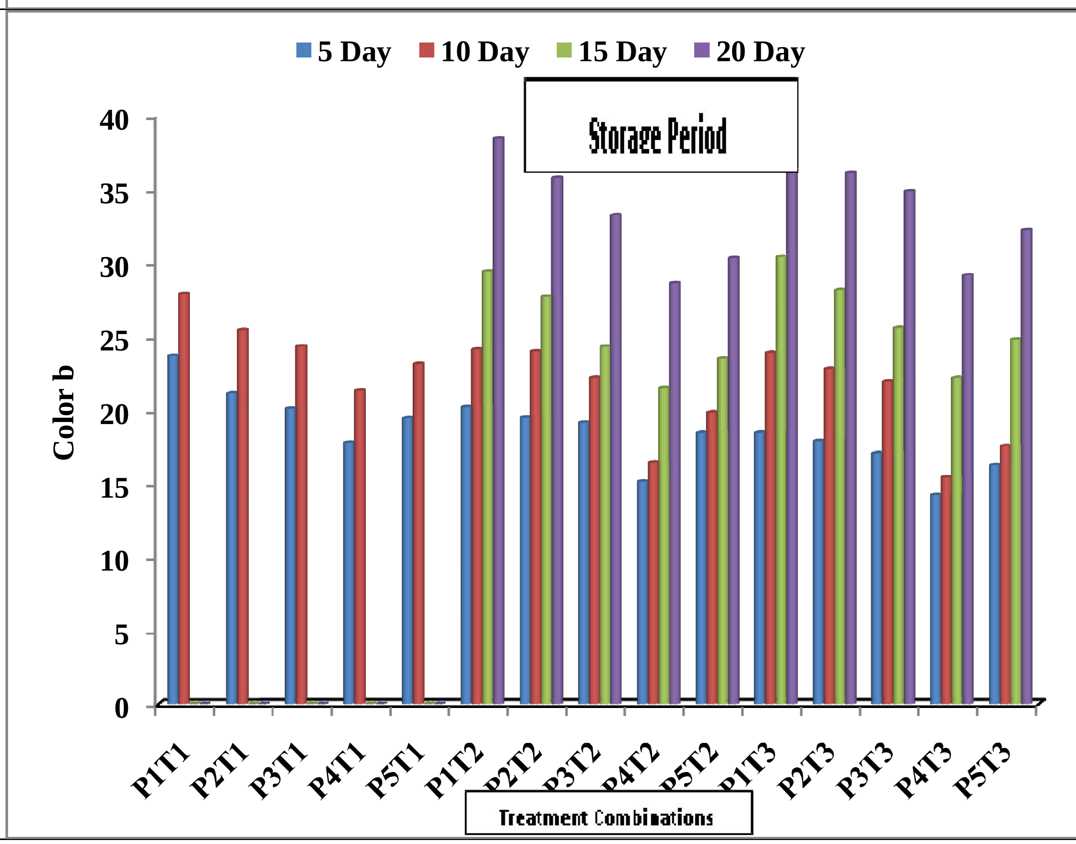
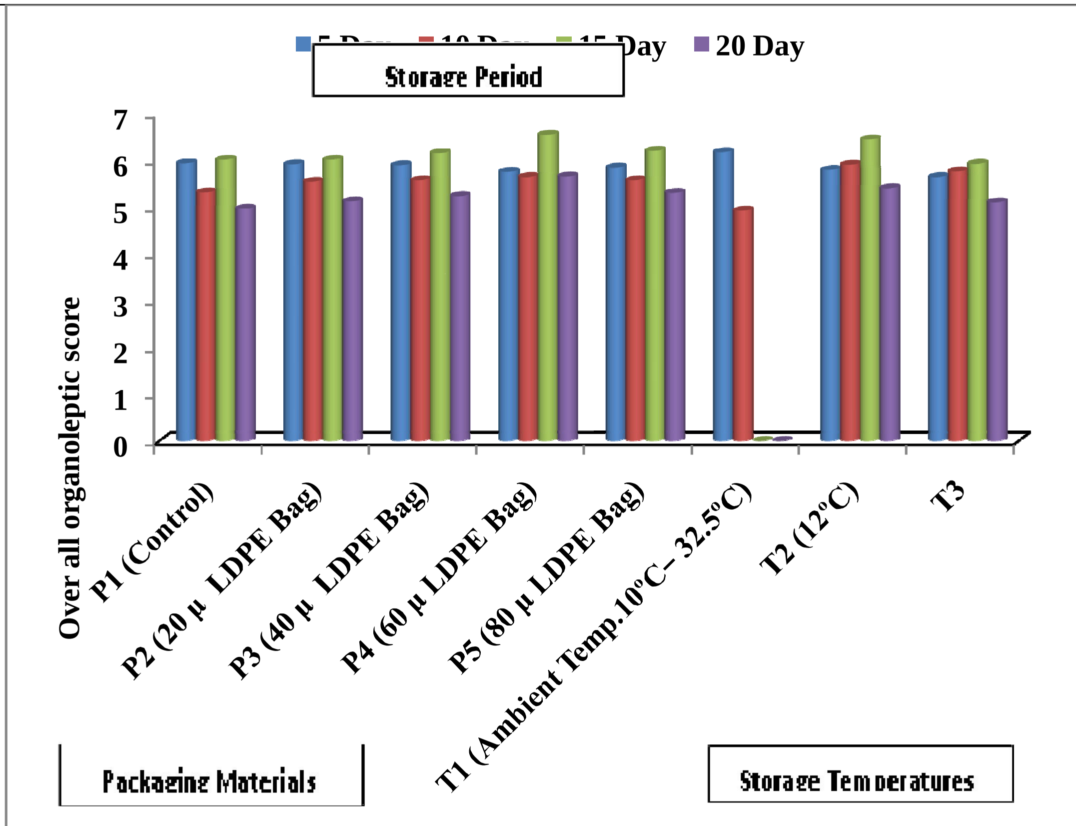


Fig. 4.13.3 Effect of packaging material, storage temperature and their interaction on Color b of tomato fruits



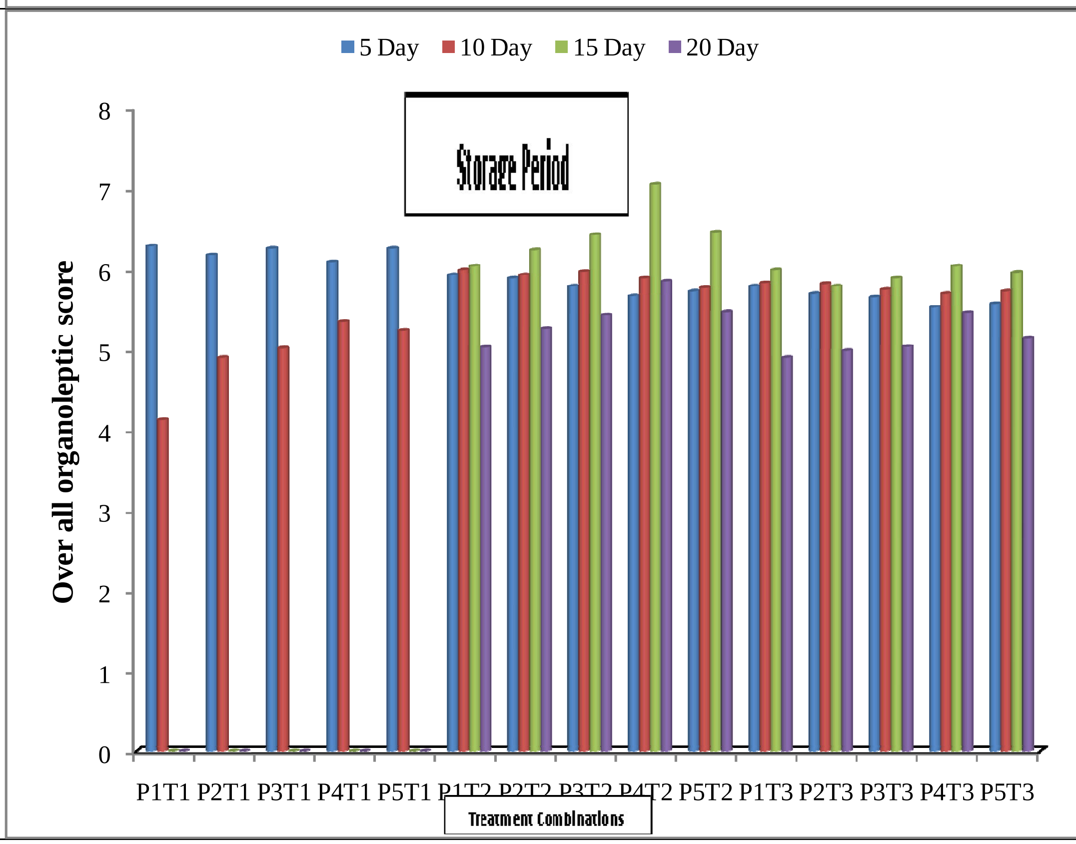
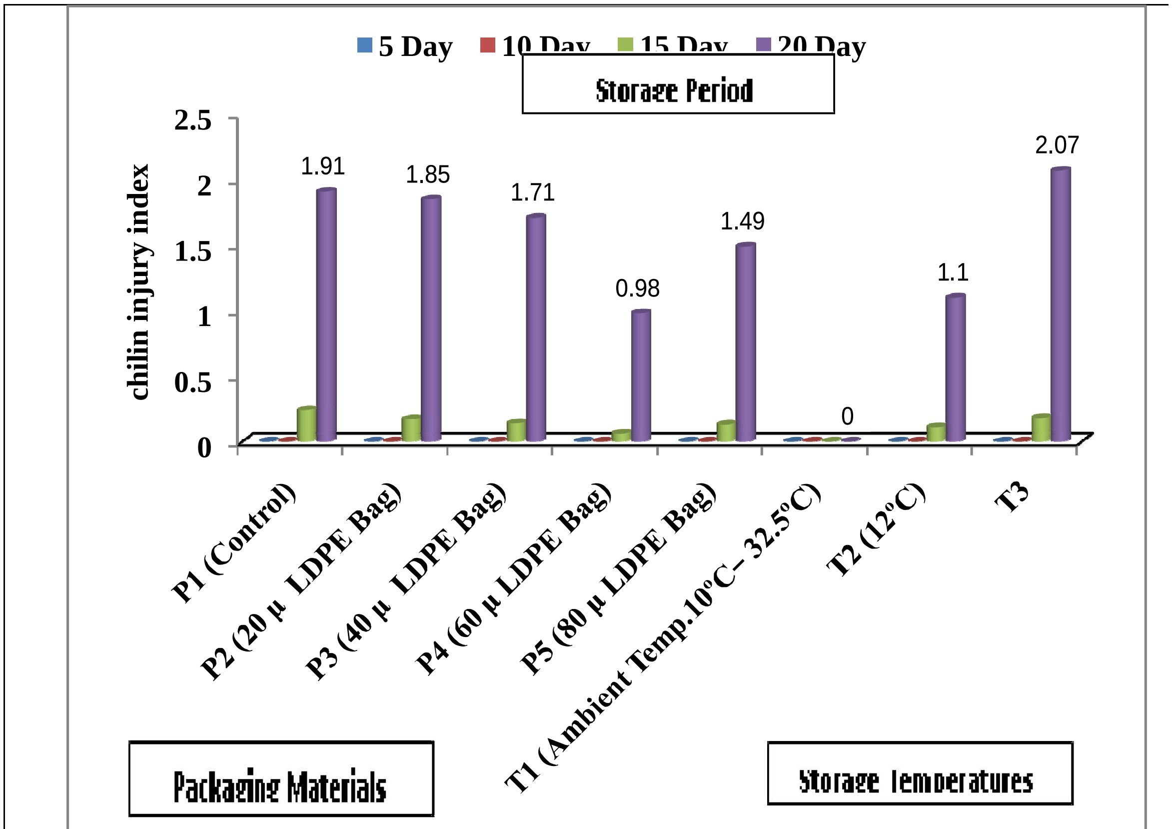


Fig. 4.14 Effect of packaging material, storage temperature and their interaction on over a organoleptic score of tomato fruits



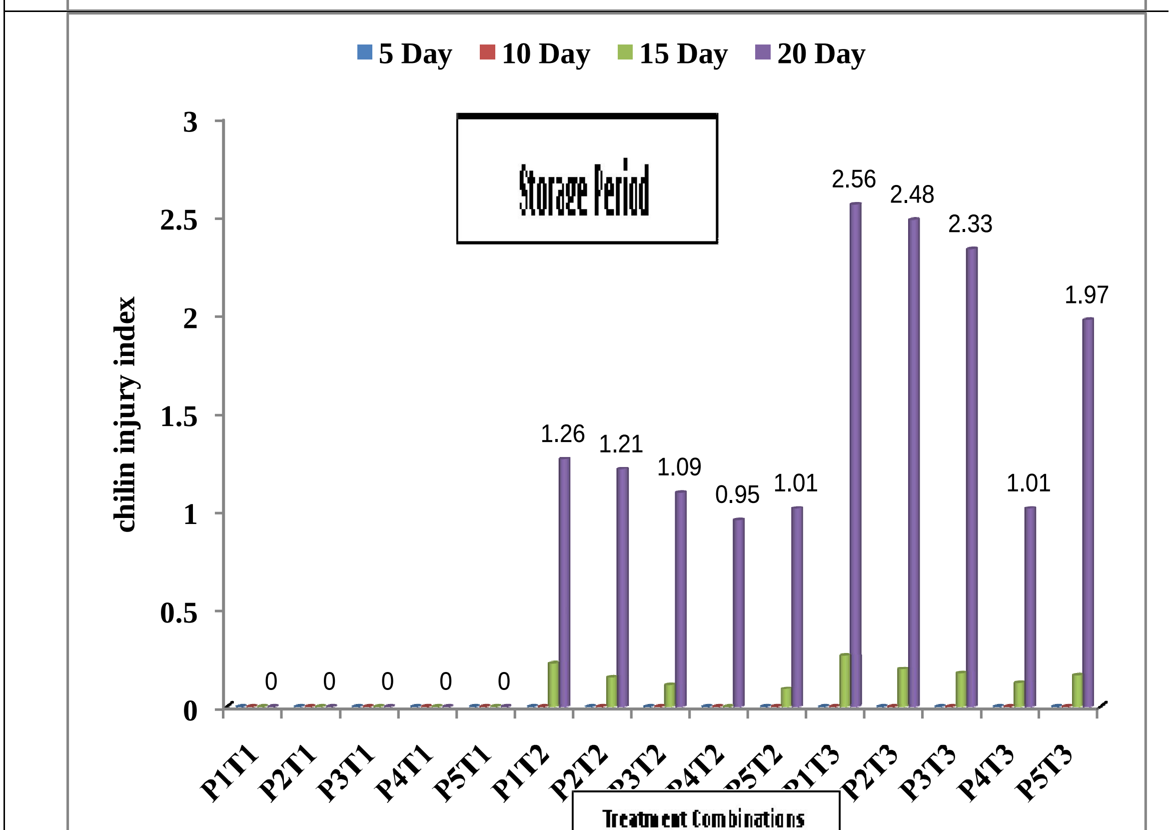


Fig. 4.15 Effect of packaging material, storage temperature and their interaction on chillin injury index of tomato fruits

5. DISCUSSION

The results of experiment entitled "Response of polyethylene packaging and storage temperature on postharvest physiology and quality of tomato" presenting in preceding chapter revealed that treatments with different packaging materials and storage temperatures on tomato fruits significantly affected by various physical, physiological, biochemical, color and sensory parameter of fruit during storage. The salient features of results obtained are discussed here under suitable headings:

5.1 Effect of temperature and packaging material on physiological characteristics

Response of polyethylene packaging and storage temperature on postharvest physiology and quality of tomato was investigated. Freshly harvested fruit at physiological maturity characterized by color turning stage were packed in four different kinds of low density polyethylene bags (20, 40, 60 and 80 µ density) and newspaper (control); and stored in at ambient, 12ºC, and 6ºC temperature for 5 day, 10 day, 15 day, and 20 day, respectively. The PLW, firmness, respiration, ethylene evaluation rate and ripening index of fruit were measured during storage (Table 4.1 to 4.5).

Effect of packaging material was observed significantly best on all physiological characters of tomato during storage and the minimum PLW (2.05%), ripening index (9.24%) and maximum respiration rate (8.01 ml CO_2 kg-1 h^{-1}), ethylene evaluation rate (7.85 µl C_2H_4 Kg^{-1} h^{-1}), firmness (42.65 N) was observed in treatment P_4 (60 µ LDPE) on 20th day. Meanwhile, the significant effect of storage temperature was also noted and the minimum PLW (2.24%), ripening index (8.85%) and maximum respiration rate (7.17 ml CO_2 kg^{-1} h^{-1}), ethylene evaluation rate (7.01 µl C_2H_4 Kg^{-1} h^{-1}), firmness (39.37 N), was observed in treatment T_2 (12^{o}C) on 20th day. Further, the combined effect of packaging material and storage temperature was observed significantly best in treatment combination of P_4T_2 (60 µ LDPE +12^{o}C) where, the minimum PLW (1.98%), ripening index (9.24%) with maximum respiration rate (9.91 ml CO_2 kg^{-1} h^{-1}), ethylene evaluation rate (7.96 µl C_2H_4 kg^{-1} h^{-1}), firmness (44.18 N) was recorded at 20th day storage.

The result showed that the use of lower storage temperatures and packaging material contributed to the significant reduction of fruit weight loss, respiration rate, ethylene evaluation rate and ripening index during storage. Climacteric rise in the rates of respiration or ethylene production was observed in harvested tomato fruit during storage, which suggests that tomato is a climacteric fruit. Similar results on fruit weight loss have been obtained in several fruits, such as loquat (Amoros *et al.*, 2008), table grape (Martinez *et al.*, 2003b), nectarines (Retamales *et al.*, 2000), peaches (Akbudak and Eris, 2004), and cherries (Kappel *et al.*, 2002; Serrano *et al.*, 2005). Among others reduction of respiration rate, a delay on climacteric respiration peak has been reported in tropical fruits (Yahia, 2006). Increase in ripening index might be due to decrease in acidity and sometimes also due to increase in TSS, similar finding also suggested by Majidi *et al.,* (2011) in tomato. PG activity in chitosan coated Jujube fruit reached a peak level 3.6-fold higher than initial activity level after 7 days storage at room temperature (Qiuping and Wenshui, 2007) in Indian jujube. Ripening of the fruit increased the pectin methyl esterase (PME) activity and Fruit firmness decrease continuously during storage, with a higher rate of decline in Chinese bayberry stored at higher temperature (Yang *et al.*, 2010).

5.2 Effect of packaging material and storage temperature on biochemical characteristics

Among the biochemical characteristics TSS (°B), acidity (%), ascorbic acid (mg $100g^{-1}$), total sugars (%), reducing sugar (%) and lycopene content (mg $100g^{-1}$) of tomato were studied during storage (Table 4.6 to 4.11). The effects of different packaging material, storage temperature and their combinations on fruit are discussed below.

The effects of different packaging material was observed significantly best on biochemical characteristics of tomato and the highest TSS (4.63°B), acidity (0.50%), ascorbic acid (28.03 mg 100^{-1}), total sugar (2.91%), reducing sugar (1.97%) and lycopene content (4.53 mg $100g^{-1}$) was recorded in treatment P_4 (60 µ LDPE) at 20th day. At the same time significant effect of storage temperature was noted on biochemical parameters of tomato and the maximum TSS (4.41°B), acidity (0.46%), ascorbic acid (25.41 mg 100^{-1}), total sugar (2.77%), reducing sugar (1.81%) and lycopene content (4.37 mg $100g^{-1}$) was noted in treatment T_2 (12°C) at 20th day of storage. Furthermore, the combined effect of packaging material and storage temperature was observed significantly best in treatment combination of P_4T_2 (60 µ LDPE +12°C) where, the superior values of TSS (4.64°B), acidity (0.51%), ascorbic acid (29.82 mg 100^{-1}), total sugar (3.01%), reducing sugar (2.00%) and lycopene content (4.60 mg $100g^{-1}$) was obtained at 20^{th} day of storage.

The result showed that the use of lower storage temperatures and an ideal packaging material contributed to the significant differences in biochemical characters. Low temperature storage has been shown to have a beneficial effect on maintaining bioactive compounds (lycopene and ascorbic acid) of fruits and vegetables, In papaya, low temperature helped in maintenance of ascorbic acid content of fruit by retaining acceptable levels of antioxidants, such as ascorbic acid and lycopene (Singh and Rao, 2005). The TSS content in the present study also correlated with the concentrations of total sugars and supported by the study of Ling *et al*. (2008).TSS increased gradually with the advancement of storage period. This might be due to moisture loss during storage. It can be also observed that TSS decreased due to over-ripening. The decrease in TSS was associated with the oxidative breakdown of sugars as a result of respiration and over ripening. Reducing sugar increased with increase in storage period. Reducing sugar increased with decrease in thickness of LDPE bags and CO_2 concentration and increase in storage temperature in sapota (Antala *et. al*., 2014) and Genanew *et. al.* (2013) in tomatoes.

5.3 Effect of packaging and storage temperature on color and sensory attribute

Decay (%), color coordinate, organoleptic score and chilling injury for tomato fruits was significantly affected by different packaging material and storage temperature during storage (Table 4.12 to 4.15).

Significant effects of different packaging material was recorded during the study and the minimum decay (13.44%), CIE L* (27.36), CIE a* (13.43), CIE b* (28.90), chilling injury (0.98) and maximum organoleptic score (5.64) was obtained in treatment P4 (60 µ LDPE) at 20th day of storage. Similarly, the effect of storage temperature on the color and sensory attributes of tomato was also found significantly best and the lowest decay (13.65%), CIE L* (37.28), CIE a* (15.56), CIE b* (33.28), chilling injury (1.10) with the highest organoleptic score (5.40) was recorded in treatment T_2 (12^{o}C) at 20th day of storage. Further, the combined effect of packaging material and storage temperature was also observed significantly best in treatment combination of P_4T_2 (60 µ LDPE +12^{o}C) where, the minimum decay (11.21%), CIE L* (30.58), CIE a* (13.41), CIE b* (28.92), chilling injury (0.98) and the maximum organoleptic score (5.84) was recorded at 20th day of storage.

Packing film exhibited lower decay than untreated fruit (control) and the result present study is evidenced by Bhatia *et al.* (2014) wherein, the packaging reduced the transpiration loss and hence reduced the physiological metabolism of the fruit and maintained fruit fresh.

The general appearance and organoleptic qualities i.e. shape, size, colour, texture, flavor and taste of the fruit altogether the consumers appeal to the fruit and are very much influenced by postharvest treatment of fruit. The overall organoleptic score of fruit initially increased, attained maximum value again which started to decline in all treatment (table 4.14). Results of present investigation are in accordance with finding of Singh and Rao (2005), who suggested that postharvest treatment conserve overall quality of tomato fruit by maintaining significantly higher levels of antioxidant, lycopene, sugar and organic acids. Being a climacteric fruit, tomato is very susceptible to low temperature injury. The commonest physiological disorder in tomato fruit is pitting. Chilling injury symptoms are dependent upon the storage temperature, as well as the duration of these temperatures. Chilling injury can occur under these conditions, as the duration of exposure to low temperature and level of fruit maturity determine its incidence and severity in tomato fruit (Prolux *et al.,* 2001).

The most striking feature was found in the morphology of overripe fruit (red colour). The middle lamellae of cell walls broke down. Cytoplasm was almost completely destroyed hence; such tomato fruit was too soft, not suitable for eating as fresh fruit (Genanew, 2013). Discoloration (L*, a* and b*) found in this study were in agreement with the work of Roberts *et al.*, (2002) and Mutari and Debbie (2011) in tomatoes.

After fruit reaching at climacteric respiration peak changed to more dark color during storage and color deteriorate very fast at higher temperature than at lower temperature as evidenced by increase of L* and C* intensities. a* and b* values also changed over time and showed continuously increase with increase in storage time.

Both the values were higher at corresponding higher temperatures. Color evaluation associated with the postharvest ripening process is generally delayed in fruits stored under low temperature, as compared to those stored in open air, as it has been shown in mango (Pesis *et al*., 2002), table grape (Martinez *et al*., 2003b) and loquat (Amoros *et al*., 2008).

6. SUMMARY

The tomato cultivar 'Dev' are generally sold in market as fresh fruits. During harvesting season, the fruits face low selling price situation due to market gluts from mid-January onward. Moreover, the fresh fruit do not keep well for a long period as such. So, storage of the fruits is necessary for sustainable crop production. By considering its necessity, the experiment entitled **"**Response of Polyethylene Packaging and Storage Temperature on Postharvest Physiology and Quality of Tomato**"** conducted in Postharvest Technology Laboratory, Department of Horticulture, Rajasthan College of Agriculture, Udaipur during month of February2017 with the following objectives.

1. To find out suitable polyethylene materials for packaging of tomato fruits.
2. To study the effect of storage temperature on postharvest physiology and quality of tomato fruits.

In order to achieve these objectives experiment with different thickness of polythene bags as packaging materials with newspaper as packets control and using three storage temperatures was conducted. The following are the salient features of the experimental findings.

1. Physiological loss in weight

The PLW of tomato fruits increased with the advancement of storage time during the entire period of experiment but lowest increase in per cent weight loss was observed in P_4 (60 micron LDPE bag) treatment with T_2 (12^{o}C) (1.98%) at 20th day storage temperature.

2. Firmness (Newton)

The firmness of tomato fruits decreased with the advancement of storage time which coincides with the ripening of fruits during the entire period of experiment in all the treatments. The minimum decline rate or maximum firmness (44.18 N) of fruits was recorded in P_4 with T_2 at 20th day.

3. Respiration rate (ml Co_2 kg^{-1} h^{-1})

The respiration rate of tomato fruits increased sharply during climacteric rise and found peak values at climacteric peak which was attained earlier in higher storage temperature with low Co_2 concentrations in packages and after that decreased with the advancement of storage time during the entire period of experiment. But at the end of experiment the lowest respiration rate (8.12 ml Co_2 kg^{-1} h^{-1}) at 20th day was noted in P_4 with T_2 temperature treatment.

4. Ethylene evolution rate (µl C_2H_4 kg^{-1} h^{-1})

The ethylene evolution rate of tomato fruits increased initially up to climacteric rise and then decreased with the advancement of storage time during the entire period of experimentation. At the end of experiment the minimum increase in ethylene evolution rate (7.96 µl C_2H_4 kg^{-1} h^{-1}) at 20th day was observed in P_4 with T_2 temperature treatment.

5. Ripening index (%)

The ripening index of tomato fruits increased initially up to climacteric rise and then decreased with the advancement of storage time during the entire period of experimentation. At the end of experiment the minimum decrease in ripening index (9.91%) at 20th day was recorded in P_4 treatments with T_2 temperature treatment.

6. Total soluble solids

The TSS (ºB) of tomato fruits increased with the advancement of storage. The rate of increase in TSS (4.64ºB) at 20th day was found lowest in P_4 treatment with T_2 storage temperature.

7. Acidity (%)

The acidity of tomato fruits decreased with the advancement of storage time during the entire period of experiment but the minimum rate of decrease or maximum retention of acidity (0.51%) at 20th day was observed in P_4 treatment with T_2 storage temperature treatment.

8. Ascorbic acid (mg $100g^{-1}$)

The ascorbic acid (mg $100g^{-1}$) content decreased with the storage period. The highest retention of ascorbic acid (29.82 mg $100g^{-1}$) at 20th day was found in P_4 treatment with T_2 storage temperature treatment.

9. Total sugars (%)

Total sugars of tomato fruits increased initially up to climacteric rise (ripening) and thereafter decreased with the advancement of storage time during the period of experiment but rate of increase was minimum (3.01%) at 20^{th} day in P_4 treatment with T_2 storage temperature.

10. Reducing sugar (%)

The reducing sugar of tomato fruits increased initially up to climacteric rise (ripening) and thereafter decreased with the advancement of storage time during the experiment but rate of increase was lowest (2.00%) in P_4 treatment with T_2 storage temperature at 20^{th} day of storage.

12. Lycopene (mg $100g^{-1}$)

The lycopene content of tomato fruits increased with the advancement of storage time during the entire period of experiment but rate of increase is highest in lycopene content was found in P_4T_2 (4.60 mg $100g^{-1}$) at 20^{th} day of storage.

13. Decay (%)

The decay percent of tomato fruits increased with the advancement of storage lowest decay per cent was observed in P_4T_2 (11.21%) at 20^{th} day of storage.

13. CIE L^* color coordinate (luminosity or lightness)

The color coordinates L^* of tomato fruits increased with the advancement of storage time during the entire period of experiment but rate of increase is minimum in color L^* (30.58) value was recorded in P_4T_2 treatment combination at 20^{th} day of storage.

14. CIE a^* color coordinate (green-red axis)

The CIE a^* color coordinate of tomato fruits increased with the advancement of storage time. The lowest increasment in CIE a^* color (13.41) value at 20^{th} day of storage was recorded in P_4 treatment with T_2 storage temperature.

15. CIE b^* color coordinate

The CIE b^* color coordinate of tomato fruits decreased with the advancement of storage time during the entire period of experiment but rate of decrease in CIE b^*

color (28.92) value was least in P_4 treatment with T_2 storage temperature at the 20^{th} day.

16. Overall organoleptic score

The overall organoleptic score (out of 10 marks) was highest (5.84) at 20^{th} day after storage in P_4T_2 treatment combination.

17. Chilling injury index

The chilling injury symptoms were occurs at 15 and 10 days of storage but the minimum chilling injury index observed (0.95) at 20^{th} day in P_4 with T_2 storage temperature while chilling injury was not seen in T_1 storage temperature.

7. CONCLUSION

On the basis of present investigation entitled "Response of Polyethylene Packaging and Storage Temperature on Postharvest Physiology and Quality of Tomato" was carried out in the Department of Horticulture, Rajasthan College of Agriculture, Udaipur during 22nd Feb.–13th March, 2017.

1. It is concluded that treatment combination P_4T_2 (60 micron LDPE bag + 12ºC storage temperature) was found best for maintaining physiological as well as qualitative attributes and increased the shelf life of tomato up to 20 days after harvest. Though, the treatment combination P_4T_2 (60 micron LDPE bag + 12ºC storage temperature) was found best but chilling injury was seen after 10 day of storage hence, further research should be conducted for the validation of the result of present study.

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