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Effect of modified atmospheric packaging on chilling injury and shelf-life of custard apple fruits

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Abstract

Laboratory experiment was conducted to study the effect of modified atmospheric packaging on chilling injury and shelf-life of custard apple fruits at the division of Postharvest Technology, Indian Institute of Horticultural Research (IIHR), Hessaraghatta, Bengaluru, during September-October, 2009. The experiment was conducted in factorial completely randomized design. Three different kinds of flexible films *viz*. low density polyethylene (LDPE), Cryovac Opti 300 and Cryovac PD-961 of 30 × 25 cm size were used for packaging of fruits as main treatment. Eight fruits were packed in each film bag and these packs were further master packed in ventilated CFB boxes. The boxes were then stored in "Walk-in" cold rooms maintained at 8, 12 and 15 °C (85-90 % RH), respectively. The observations were recorded at weekly intervals. Results of the study revealed that MAP of custard apple fruits with LDPE or Cryovac PD-961 film could alleviate the chilling injury at 8 °C to considerable extent, besides extending the storage life. The non-packed control fruits could be stored up to three weeks at 8 °C, but these fruits lacked desirable appearance due to development of chilling injury. At 12 °C, the fruits could be kept in unripe condition up to two weeks, when the fruits were packed either in LDPE or Cryovac PD-961 film, when compared to four days in non-packed fruits at room temperature. These fruits ripened normally without chilling injury (CI) in three days when they were shifted to RT after unpacking. It can be concluded that the storage life of custard apple fruits could be extended at 12 °C without any CI by packing the fruits in LDPE or Cryovac PD-961 film.

Key words: MAP, custard apple, *Annona squamosa,* ripening rate, chilling injury, firmness, TSS, packaging film, temperature

Introduction

Custard apple fruits are highly perishable with a very short post harvest shelf life of 3 to 4 days under ambient conditions. The safe range of storage temperature for further extension of storage life was found to be between 15 and 20 °C with maximum storage life of 9 days at 15 °C (Vishnu Prasanna *et al.,* 2000). Below this storage temperature the fruits are susceptible to chilling injury with fruits becoming hard with surface blackening and messy pulp. Modified atmospheric packaging is reported to alleviate chilling injury in many tropical and subtropical fruits (Yahia and Paull, 1997).

The process of ripening can be controlled to certain limits by monitoring the storage conditions. *Annona squamosa* L. being tropical in origin is reported to be highly sensitive fruit to chilling temperatures and develops symptoms of blackening when it falls below 10 °C (Ke *et al.,* 1983). When a commodity is continuously respiring, it leads to the exhaustion of O_2 inside the pack and there is generally a buildup of CO_2 and equilibrium is reached when the rate of respiration is equal to the rate of permeation and as a consequence, steady concentration of O_2 and CO_2 are maintained (Singh, 2003)

Custard apple ripens normally at storage temperatures of 15 to 30°C, but the fruits are susceptible to fungal attack at temperatures higher than 25 °C (Broughton and Guat, 1979). The fruits stored at 20 °C were optimum for eating quality and storage, while storing at 0.5 to 10 °C resulted in chilling injury. Physiologically matured fruits held at 12.5 °C had acceptable eating quality for over 7 days, but at 20 and 25 °C fruits lost eating quality within three days (Flores, 1982). According to Tsay and Wu (1989), the fruits of *A. suqamosa* stored at 28 °C softened by fourth day and those at 20 °C by sixth day during storage, but those at 16 °C did not ripe completely even on 14th day.

Hence, the present investigation was carried out to study the effect of MAP to alleviate the chilling injury of custard apple fruits, using three different polymeric films *viz.,* low density polyethylene (LDPE), Cryovac Opti 300 and Cryovac PD-961.

Materials and methods

The fully mature green fruits were selected for the experiment when the area between two segments turned into cream colour. The fruits were kept in the plastic crates with cushion at the bottom.

The fruits were sorted out (immature fruit, misshapen fruits were rejected) and graded for uniform size. To maintain homogeneity in the experiment, medium size fruits were selected *i.e.*, fruits of weight 120-180 g. The fruits were then cleaned by dry brushing to remove mealy bugs, dust, dirt *etc.* Eight fruits were sealed in each films and each film had 3 replications. The dimensions of film were 30 × 25 cm. After packing the fruits the packs were master packed in ventilated CFB boxes. The CFB boxes containing the packed fruits were stored in "Walk-in" cold rooms maintained at 8, 12 and 15 °C (85-90 % RH), respectively. After storage intervals (weekly), the fruits were unpacked and allowed to ripe at room temperature in the laboratory (26-32 °C) and the observations were recorded. The details of the permeability of the films used for packaging is given in the following table:

Film	Permeability		
	O_2 (mL m^{-2} day^{-1} atm^{-1})	CO_2 (mL m^{-2} day^{-1} atm^{-1})	WVTR (g m^{-2} day^{-1} at 38 °C 90 % RH)
LDPE	3900-13000	7700-77000	10-12
Cryovac Opti 300	8500-11500	26000-30000	15-23
Cryovac PD 961	7400-8500	21000-24000	9-14

The chilling injury (%) was expressed with the help of visual observations and the scores were given according to its severity, score 1 was given to 0 per cent chilling injury, likewise score 2 (0-25 per cent), 3 (25-50 per cent), 4 (50-75 per cent) and 5 (75-100 per cent) was given to denote the severity.

The ripening rate was recorded by visual observation by giving scores according to its ripening stage and the score 1, 2, 3, 4, 5 and 6 were given for the stages unripe (UR), quarterly ripe (QR), semi-ripe (SR), 3/4th ripe, full ripe(FR) and over ripe (OR), respectively.

The gas composition (O_2 and CO_2) percentage inside the modified atmosphere packs, firmness (kg/cm^2) of fruit and total soluble solids (°Brix) were measured by auto gas analyzer (Model: Checkmate 9900 O_2/CO_2, Denmark), Instron-Universal testing machine (Model: 4201, USA) and hand refractometer (Make: Erma, Tokyo, Japan), respectively.

Results and discussion

Chilling injury: Chilling injury symptoms like skin discolouration, surface blackening, messy pulp and failure to ripe normally were observed when the commodity is removed to room temperature during the study. The chilling injury incidence was observed more in the fruits stored at 8 °C compared to the fruits stored at 12 °C, whereas the incidence was negligible in the fruits of 15 °C. Modified atmospheric packing significantly reduced the severity of chilling injury at 8 and 12 °C. After one week storage, at 8 °C, the chilling injury index was lower in all packs as compared to non-packed control (Table 1a). The chilling injury index in the fruits packed in LDPE and Cryovac Opti 300, stored at 8 °C was same (1.06), whereas in Cryovac PD-961 it was 1.11 but in control it was more *i.e.* 1.72. The chilling injury in the fruits stored at 12 and 15 °C was negligible and was same in all packs and slightly high in control. The control fruits, when shifted to room temperature after storage at 8 °C, showed increase in CI index as the days of storage increased, but the fruits which were unpacked from films were showing less symptoms of chilling injury. While, the fruits stored at other two temperatures (12 and 15 °C), the chilling injury was not seen as the days of storage at room temperature increased. In general, the chilling injury index in custard apple fruits was inhibited by LDPE film as compared to control.

When the fruits were stored for two weeks, the chilling injury index at 8 °C was lower in all packs as compare to non-packed control. It was recorded least in LDPE (1.28) as compare to control (2.34). The CI index in the fruits stored at 12 °C was not influenced by the packaging film and it was same as control, while at 15 °C chilling injury index was negligible (Table 1b). The fruits stored at 8 °C, when shifted to room temperature, the chilling injury index increased as the days of storage increased. It was recorded higher in non-packed control fruits (2.47) and least in Cryovac PD-961 (1.65).

Table 1a. Chilling injury of custard apple fruits during storage at low temperature and after shifting to room temperature for ripening

	One week at low temperature				+ two days at room temperature				+ three days at room temperature				+ four days at room temperature			
	8 °C	12 °C	15 °C	Mean (P)	8 °C	12 °C	15 °C	Mean (P)	8 °C	12 °C	15 °C	Mean (P)	8 °C	12 °C	15 °C	Mean (P)
LDPE	1.06	1.06	1.00	1.04	1.06	1.00	1.00	1.02	1.07	1.00	1.00	1.02	1.07	1.00	1.00	1.02
Cryovac Opti 300	1.06	1.00	1.05	1.03	1.13	1.00	1.00	1.04	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Cryovac PD- 961	1.11	1.11	1.05	1.09	1.28	1.00	1.00	1.09	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Control (non-packed)	1.72	1.14	1.13	1.33	2.12	1.10	1.00	1.40	2.43	1.00	1.00	1.48	2.43	1.11	1.00	1.51
Mean Temperature (T)	1.24	1.08	1.06		1.40	1.02	1.00		1.37	1.00	1.00		1.37	1.03	1.00	
LSD (*P*=0.05)	T	P	T × P		T	P	T × P		T	P	T × P		T	P	T × P	
	0.121	0.14	0.242		0.217	0.25	0.433		0.213	0.246	0.427		0.218	0.252	0.437	

Table 1b. Chilling injury of custard apple fruits during storage at low temperature and after shifting to room temperature for ripening

	Two weeks at low temperature				+ two days at room temperature				+ three days at room temperature			
	8 °C	12 °C	15 °C	Mean (P)	8 °C	12 °C	15 °C	Mean (P)	8 °C	12 °C	15 °C	Mean (P)
LDPE	1.28	1.17	1.21	1.22	1.33	1.00	1.00	1.11	1.87	1.00	1.00	1.29
Cryovac Opti 300	1.89	1.11	1.00	1.33	1.67	1.00	1.00	1.22	1.97	1.00	1.00	1.32
Cryovac PD- 961	2.06	1.28	1.00	1.44	1.67	1.00	1.00	1.22	1.65	1.00	1.00	1.22
Control (non-packed)	2.34	1.17	1.00	1.50	1.73	1.00	1.00	1.24	2.47	1.00	1.00	1.49
Mean Temperature (T)	1.89	1.18	1.05		1.60	1.00	1.00		1.99	1.00	1.00	
LSD (*P*=0.05)	T	P	T × P		T	P	T × P		T	P	T × P	
	0.197	NS	0.394		0.162	NS	NS		0.103	0.119	0.205	

The chilling injury was noticed higher in fruits stored at 8 °C compared to higher temperature. However, MAP could significantly inhibit the chilling injury after one week storage, but the similar results could not be seen as the storage duration increased. This may be due to failure of MAP to alleviate the chilling injury beyond certain period (Kader, 1986; Li and Kader, 1989).

Gas composition during storage: The films could significantly maintain the lowest O_2 concentration and highest CO_2 concentration compared to atmosphere. Lowest O_2 concentration was observed LDPE (11.97 %) after 21 days of storage at 8 °C, highest CO_2 concentration was observed in same film (10.5 %) followed by two other films (Fig. 1a). While, the lowest O_2 concentration was recorded in Cryovac PD 961 (4.69 %) and the highest CO_2 concentration was recorded with same film (23.33%) when the fruits were stored at 12 °C, at 21st day of storage (Fig.1b).

The gas composition inside the packs could significantly alleviate the chilling injury as compared to non-packed ones. But, due to high concentration of CO_2, the flavour of fruit became off when the fruits were stored for 21 days at 8 °C. The colour of fruits at 21st day of storage was slightly degraded as compared to fresh ones; this may be due to the higher concentration of CO_2 and lower concentration of O_2 inside the pack. This effect of CO_2 and O_2 was also reported by Srinivasa *et al.* (2002) in mango and Singh (2003) in papaya.

Ripening rate: Temperature, film and combination played important role on the ripening rate. When the fruits were stored for different storage intervals *viz.,* one week and two weeks, the temperature and packaging film individually reduced the ripening percentage significantly and this was observed in all storage intervals (Table 2 and 3)

It was observed that, as the storage temperature decreased the rate of ripening also decreased, while amongst the films, LDPE could significantly reduce the ripening rate as compare to non-packed control fruits and that of other films also. During ripening, after shifting to room temperature, the fruits which were stored at 12 °C ripened normally compared to the fruits which were stored at 8 °C, this may be due to development of chilling injury in the fruits stored at 8 °C as a result of hardness of surface. The fruits which were packed in LDPE film, when unpacked, showed normal ripening behavior compared to non-packed control and that of other two films. Non-packed fruits stored at 8 °C failed to ripe properly compared to fruits stored at 12 °C packed in Cryovac PD-961. The failure of ripening or normal ripening behavior of the fruits stored at 8 °C could be due to the gas composition (Srinivasa *et al*., 2002).

Firmness: The results obtained showed that the storage temperature, film and interaction had great impact on the retention of firmness during storage at different storage interval *viz.,* one week and two weeks (Table 4). The fruits stored at 8 °C maintained the highest firmness during both storage interval which was significantly higher than those stored at either 12 or 15 °C (Table 4). The retention of firmness is may be due to the gas composition inside the pack (Srinivasa *et al*., 2002). The results showed that, when these fruits were shifted to room temperature after storage at low temperature, there was drastic reduction in the firmness of fruits during their ripening (Table 4).

The storage temperature influenced the retention of firmness even after ripening. The fruits stored at 8 °C ripened normally compared to the fruits stored in other two temperatures. The gas composition inside the packs could have resulted in accelerating the ripening rate when the fruits were unpacked (Srinivasa *et al*., 2002). The interaction effect of storage temperature and packaging film revealed that the firmness of fruits packed in Cryovac Opti 300 and stored at 15 °C for one week had better firmness value (9.44 kg/cm^2) even at ripe stage as compare to any other treatment. When the fruits stored for two weeks control fruits retained better firmness than the packed ones. This may be due to development of chilling injury in control fruits and packed fruits ripened normally.

The retardation of firmness losses might be due to reduced activity of cell wall enzymes under modified atmosphere conditions (Salunke and Kadam, 1995; Singh, 2003; Kader, 1986). It is evident from the results that the firmness loss was gradual at low temperature (8 °C) compared to high temperature (15 °C). However, the loss of firmness increased with the prolonged storage. The increase in firmness in control fruits stored at 8 °C was due to skin hardening as a result of chilling injury.

Total soluble solids: The storage temperature and packaging film both significantly affected the changes in total soluble solids in

Table 2. Ripening rate of custard apple fruits during one week storage at low temperature and after shifting to room temperature for ripening

	One week at low temperature				+ two days at room temperature				+ three days at room temperature				+ four days at room temperature			
	8 °C	12 °C	15 °C	Mean (P)	8 °C	12 °C	15 °C	Mean (P)	8 °C	12 °C	15 °C	Mean (P)	8 °C	12 °C	15 °C	Mean (P)
LDPE	1.06	1.28	1.41	1.25	1.80	2.27	2.01	2.03	2.13	3.00	2.78	2.64	2.13	3.13	2.98	2.75
Cryovac Opti 300	1.22	1.81	2.03	1.69	2.07	3.41	2.92	2.80	2.07	3.40	1.92	2.46	2.10	3.73	2.00	2.61
Cryovac PD- 961	1.22	1.00	1.62	1.28	1.78	1.64	2.76	2.06	1.93	1.90	2.51	2.11	2.53	2.10	2.74	2.46
Control (non-packed)	1.06	1.68	1.88	1.54	1.56	2.85	3.15	2.52	2.19	3.33	2.28	2.60	2.26	3.33	2.28	2.62
Mean Temperature (T)	1.14	1.44	1.73		1.80	2.54	2.71		2.08	2.91	2.37		2.26	3.08	2.50	
	T	P	T × P		T	P	T × P		T	P	T × P		T	P	T × P	
CD @ 5%	0.29	0.34	NS		0.56	NS	NS		0.422	NS	0.843		0.444	NS	0.889	
SEm ±	0.102	0.117	0.203		0.193	0.223	0.386		0.145	0.167	0.289		0.152	0.176	0.304	
F- test	**	*	NS		**	NS	NS		**	NS	*		**	NS	*	

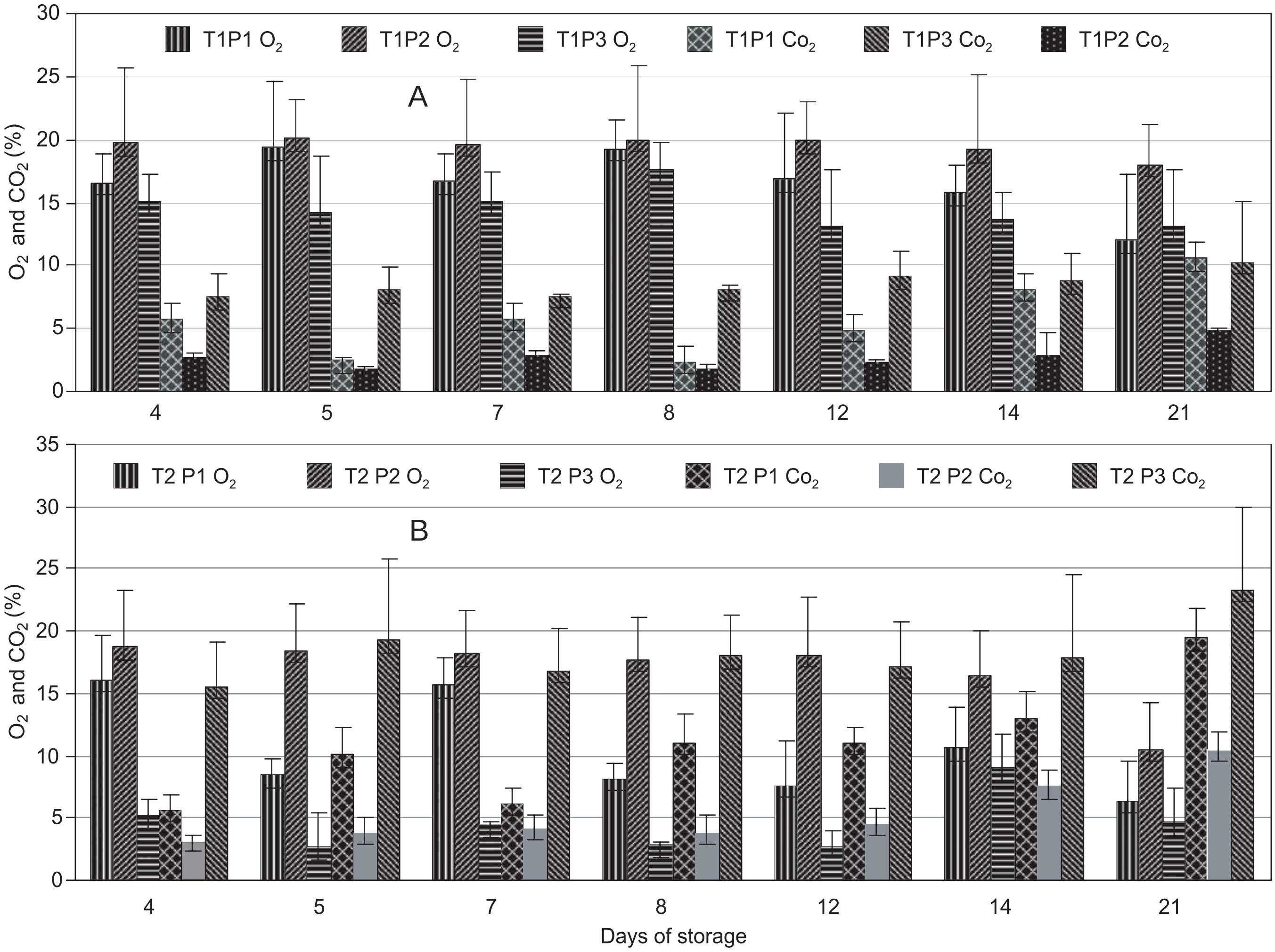

Fig. 1. Gas composition inside modified atmospheric pack during storage A) at 8 °C and B) at 12 °C

Table 3. Ripening rate of custard apple fruits during two weeks of storage at low temperature and after shifting to room temperature for ripening

	Two weeks at low temperature				+ two days at room temperature				+ three days at room temperature			
	8 °C	12 °C	15 °C	Mean (P)	8 °C	12 °C	15 °C	Mean (P)	8 °C	12 °C	15 °C	Mean (P)
LDPE	1.68	1.33	3.26	2.09	1.40	2.00	3.82	2.41	1.67	2.21	4.75	2.87
Cryovac Opti 300	1.17	2.81	4.17	2.72	1.87	2.69	4.17	2.91	2.29	2.67	2.74	2.56
Cryovac PD- 961	1.06	1.33	2.78	1.72	1.54	1.62	3.38	2.18	1.77	1.58	2.60	1.98
Control (non-packed)	1.39	1.67	2.61	1.89	1.82	2.33	2.60	2.25	2.18	2.76	2.48	2.47
Mean Temperature (T)	1.32	1.79	3.21		1.66	2.16	3.49		1.97	2.31	3.14	
	T	P	T × P		T	P	T × P		T	P	T × P	
CD @ 5%	0.459	0.531	NS		0.521	NS	NS		0.354	0.408	0.707	
SEm ±	0.157	0.182	0.315		0.179	0.206	0.357		0.121	0.14	0.242	
F- test	**	**	NS		**	NS	NS		**	**	**	

fruits. At higher temperature it is obvious that increase in TSS will be more and the same was observed in this study.

The storage temperature influenced the changes in TSS to a greater extent as evident from the results. The rate of increase in TSS was more in fruits stored at 15 °C followed by 12 °C and 8 °C (Table 5). This indicates that the ripening process initiated during storage itself at higher temperature (15 °C).

The metabolic process related to the advanced ripening resulted higher TSS, probably due to disassociation of some molecules and structural enzymes in soluble compounds (Lyon *et al*., 1992).

Increase in TSS during ripening might have resulted from an increase in concentration of organic solutes as a consequence of water loss. Increase in TSS may also occur due to numerous anabolic and catabolic processes taking place in the fruit, preparing it for senescence (Smith *et al*., 1979).

Modified atmosphere packaging of custard apple fruits with

Table 4. Influence of MAP on firmness (kg/cm²) of custard apple during storage at low temperature and after ripening at room temperature

	After one week storage at low temperature				After ripening at room temperature				After two weeks storage at low temperature				After ripening at room temperature			
	8⁰C	12⁰C	15⁰C	Mean (P)	8⁰C	12⁰C	15⁰C	Mean (P)	8⁰C	12⁰C	15⁰C	Mean (P)	8⁰C	12⁰C	15⁰C	Mean (P)
LDPE	47.51	18.65	11.81	25.99	5.23	7.26	6.06	6.18	35.45	35.11	8.13	26.23	4.70	5.93	1.83	4.15
Cryovac Opti 300	42.37	28.32	6.46	25.72	4.28	5.22	9.44	6.31	35.90	8.24	2.30	15.48	6.26	4.03	2.73	4.34
Cryovac PD- 961	39.08	38.96	3.86	27.30	4.23	7.49	6.92	6.21	34.77	44.55	22.93	34.08	5.51	5.79	3.90	5.07
Control (non-packed)	52.04	22.16	7.74	27.31	4.43	4.02	7.78	5.41	18.51	14.28	4.74	12.51	5.51	7.78	3.89	5.73
Mean Temperature (T)	45.25	27.02	7.47		4.54	6.00	7.55		31.16	25.54	9.52		5.49	5.88	3.09	
	T	P	T × P		T	P	T × P		T	P	T × P		T	P	T × P	
CD @ 5%	4.258	NS	8.515		0.715	NS	1.431		2.588	2.988	5.175		0.841	0.971	1.683	
S.Em. ±	1.459	1.684	2.917		0.245	0.283	0.49		0.887	1.024	1.773		0.288	0.333	0.576	
F- test	**	NS	**		**	NS	**		**	**	**		**	*	*	

Table 5. Influence of MAP on T.S.S. (°B) of custard apple fruits during storage at low temperature and after ripening at room temperature

	After one week storage at low temperature				After ripening at room temperature				After two weeks storage at low temperature				After ripening at room temperature			
	8⁰C	12⁰C	15⁰C	Mean (P)	8⁰C	12⁰C	15⁰C	Mean (P)	8⁰C	12⁰C	15⁰C	Mean (P)	8⁰C	12⁰C	15⁰C	Mean (P)
LDPE	22.23	24.77	25.00	24.00	25.37	24.80	25.67	25.28	21.33	19.33	21.93	20.87	22.50	22.25	24.60	23.12
Cryovac Opti 300	20.57	25.47	24.13	23.39	23.83	24.60	25.47	24.63	18.53	22.47	22.93	21.31	23.70	25.20	20.40	23.10
Cryovac PD- 961	21.60	23.77	21.70	22.36	24.80	23.33	26.10	24.74	20.67	21.67	23.00	21.78	24.50	23.40	21.20	23.03
Control (non-packed)	24.77	26.70	26.20	25.89	27.53	26.13	26.20	26.62	21.93	24.13	24.90	23.66	23.70	25.20	21.20	23.37
Mean Temperature (T)	22.29	25.18	24.26		25.38	24.72	25.86		20.62	21.90	23.19		23.60	24.01	21.85	
	T	P	T × P		T	P	T × P		T	P	T × P		T	P	T × P	
CD @ 5%	1.379	1.592	NS		NS	NS	NS		1.614	1.863	NS		0.276	NS	0.551	
S.Em. ±	0.472	0.545	0.945		0.722	0.834	1.445		0.553	0.638	1.106		0.094	0.109	0.189	
F- test	**	**	NS		NS	NS	NS		*	*	NS		**	NS	**	

LDPE or Cryovac PD-961 film could alleviate the chilling injury and extend the storage life and maintain the quality up to two weeks at low temperature over 4 days in non-packed fruits at normal ripening. At low temperature (8 °C), the fruits could be stored up to 3 weeks without affecting the quality parameters but the appearance of fruits was not desirable due to development of chilling injury. Whereas, the storage life of custard apple fruits could be extended up to two weeks when packed in LDPE or Cryovac PD-961 film and stored at 12 °C, without any chilling injury symptoms and the fruits ripened normally in 3 days at room temperature. When the fruits were stored at 15 °C, it could be stored up to 2 weeks in acceptable form, but the fruits started the ripening during storage inside films only.

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