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Effect of storage conditions and packaging material on postharvest quality attributes of strawberry

Samina Khalid[1*], Maria Majeed[1], Muhammad Irfan Ullah[2], Muhammad Shahid[1], Abdur Rehman Riasat[1], Tahira Abbas[3], Hafiz Muhammad Aatif[3] and Amjad Farooq[1]

1, *Department of Environmental Sciences, COMSATS University Islamabad, Vehari Campus, Pakistan*
2, *Department of Entomology, University of Sargodha, Sargodha (40100), Pakistan*
3, *Bahuddin Zakariya University, Bahadur Sub-Campus Layyah, Punjab, Pakistan*

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***Corresponding author:**
Department of Environmental Sciences, COMSATS University Islamabad, Vehari Campus, Pakistan.
Email: saminakhalid@ciitvehari.edu.pk

ABSTRACT

Purpose: Strawberry (*Fragaria* × *ananassa*) is highly perishable fruit with a limited postharvest life at room temperature and is vulnerable to postharvest decay due to its high respiration rate, environmental stresses and pathogenic attacks. **Research method:** To increase the postharvest life of strawberries, a combination of packaging material (polyethylene and perforated polyethylene) along with control and storage conditions {zero energy cool chamber (ZECC) and ambient conditions in laboratory} were tested. **Main findings:** Mass loss (1.59%) and internal temperature (22.24°C) were significantly reduced while shelf-life (more than 3 days) was enhanced in ZECC as compared to ambient conditions in laboratory with 6.46% mass loss, 23.04°C internal temperature and less than 3 days shelf-life. Packaging material significantly influenced mass loss (%) and electrical conductivity (S/m) of strawberry juice irrespective of its interaction with storage conditions and storage durations. Maximum mass loss (9.11%) and EC (3.74 S/m) were recorded in control samples while, minimum mass loss (1.24%) and EC (3.52 S/m) was recorded in polyethylene enclosed fruit. Irrespective of storage conditions and packaging material pH, TSS, titratable acidity (%) and ascorbic acid (mg100 ml^{-1}) decreased while electrical conductivity (S/m) increased during storage. **Limitations:** In future study storage duration should be extended by adding more removals to get clear difference in fruit quality and shelf-life under various treatments. **Originality/Value:** In conclusion ZECC can be used for short term storage of strawberry.

INTRODUCTION

Strawberry (*Fragaria* × *ananassa*) is well-known as the most appetizing and very nutritive fruit. It is the richest source of bioactive compounds with antioxidant activity (Yang et al., 2016) which provide protection against harmful free radicals. In Pakistan, it is consumed in fresh as well as in processed form for making squashes, jams and jellies which may be used throughout the year. Strawberry mainly growing in northern areas of the country like Swat, Charsadda, Mansehra, Haripur, Abbottabad, Mardan, Peshawar and some parts of central and south Pakistan like Gujrat, Sialkot, Jhelum, Chakwal, Multan and Karachi (Murtaza, 2014). Varieties like 'Chandler', 'Corona' 'Douglas','Tufts', 'Gorella'and 'Toro' are locally cultivated in various parts of Pakistan (Memon, 2014).

Strawberry is a highly perishable fruit having high respiration rate (50-100 ml CO_2 per kg of fruits per hour at 20°C), and can be stored only for four days (Panda et al., 2016). In Pakistan postharvest losses in strawberry are pretty high over 40%, of which 10% at farm level, 14% during transport and 23% at retail and these losses are mainly due to non-selective harvesting, poor packaging, transportation and almost absence of cold chain (Rajwana et al., 2016). To slow metabolic processes and reduce deterioration prior to transport, low temperatures are widely used to reduce spoilage and extend the shelf-life of fresh produce (Van, 2013). Storage temperature had significant influence on quality and bioactive compounds of strawberry. Strawberries could be kept for acceptable period of time at 10°C and could be stored for longer duration at 0.5°C (Shin et al., 2007). Higher level of total phenolics and total anthocyanin contents were found when strawberries were kept at 10°C than those stored at 0°C or 5°C (Jin et al., 2011). Mechanical refrigeration is expensive and requires power supply which is not easily available in Pakistan. Mechanical refrigeration is also not environment friendly because it releases chlorofluorocarbons and hydro chloroflorocarbons in the environment that is responsible for ozone layer depletion and global warming (Xuan et al., 2012).

Evaporative cooling is an efficient and economical method for reducing produce temperature and increasing relative humidity to decrease the physical mass loss and diseases incidence (Odesola & Onyebuchi, 2009). The ZECC work on the principle of evaporative cooling and can help to save fresh fruits and vegetables for a reasonable period of time (Jha & Kudos, 2006). The greatest importance of this low cost cooling technology lies in the fact that it does not require any electricity or power to operate and all the material requires to make the cool chamber is cheap and locally available.

The high postharvest losses has been attributed to several factors among which lack of packaging and storage facilities and poor means of transportation are the major ones (Kebede, 1991; Wolde, 1991). Packaging fruits is one of the most commonly used postharvest practice as unitized volumes are easier to handle achieve protection from hazards associated with transportation and storage (Burdon, 2001). Packaging of fruits with polymeric films is often used to prevent moisture loss, to protect against mechanical damage, and to achieve a better appearance (Hening & Gilbert, 1975). Packaging of fruits in polyethylene films creates modified atmosphere conditions around fruits which trigger the rise of CO_2 and fall in O_2 concentration inside package resulting in reduced rate of respiration, transpiration and other metabolic processes of fruit (Singh et al., 2018). Wrapping of strawberries in plastic film reduced ascorbic acid loss by 5-folds at 1 and 10°C and 2-folds at 20°C (Nunes et al., 1998).

The evaporative cooled storage combined with packaging improved the shelf-life of papaya fruits by more than two folds (Azene et al., 2014). Pear fruit individually packed in polyethylene bag (0.05 or 0.01 mm) and stored at ZECC efficiently preserved fruit quality parameters (Singh et al., 2017). In an experiment conducted in Gujarat, India Kanak and Sanjay (2013) reported that jamun (cv *Goma priyanka*) fruits packed in perforated polythene bag and stored in ZECC performed best and displayed 4 days shelf-life, while fruit kept at ambient conditions had one day shelf-life. Prasad et al. (2015) reported that packaging of banana fruits in high and low density polyethylene bags resulted in longer shelf-life and improved produce quality. Individual packing of pear fruit in polyethylene bags of 0.01 mm and storage under ZECC proved to be most effective treatment in reducing physiological losses in mass (Singh et al., 2018). The shelf-life of custard apple fruits was 9 days in ZECC when wrapped with tissue papers and kept in cardboard boxes as compared to 6 days under ambient storage (Patil et al., 2011).

Therefore, present investigation was conducted to study the effect of packaging materials on strawberry quality attributes under ZECC storage.

MATERIALS AND METHODS

Plant material and experimental site

The experiment was conducted at Department of Environmental Sciences, COMSATS University Islamabad, Vehari Campus. Strawberry cv. 'Chandler' was harvested at red ripe stage from farmers field located at Arien vhin Mailsi, Punjab, Pakistan.

Experimental procedure

Fruit were brought to laboratory, sorted and divided into 36 lots comprising of 8 fruit per lot. Each lot of fruit was kept in styrofoam clamshell container and each container was individually wrapped in polyethylene and perforated polyethylene bags, control containers were kept unwrapped. A factorial experiment was conducted in completely randomized design and different packaging material (wrapped in polyethylene and perforated polyethylene bag) along with no-wrapping as control, storage conditions (ZECC and ambient conditions) and also different storage durations (at harvest, middle and end of storage period) were considered as experimental factors with three replications (3×2×3×3=36). The thickness and mass of polyethylene bag was 0.016 mm and 4.10g and perforations were at 4×3.5 cm distance in case of perforated polyethylene bag.

Construction of ZECC

The ZECC was constructed as described by Pal and Roy (1988). On rectangular floor a double walled structure was erected with bricks having a cavity which is filled with fine sand. Inside the cavity a frame of rectangular plastic pipe having small holes was laid on the sand bed. Rectangular frame was connected with water tank kept on raised stand. Water is applied in the form of small droplets to moisten the sand filled in the cavity. Plastic crates were used to keep strawberry inside the ZECC and top of which were covered with wet gunny bags. The whole structure was covered under shed to prevent sunlight and rain (Fig. 1).

Temperature (°C) and relative humidity (%)

Temperature (°C) and relative humidity (%) was determined with the help of thermo-hygrometer (TFA Dostman/D-97877 Wertheim) three times a day of both ZECC and Laboratory.

Physical quality parameters

Mass loss (%) and shelf-life (days)

Mass of strawberries was determined at start, middle and end of the experiment. The mass loss percentage was calculated by following formula (1):

$$\text{Mass loss (\%)} = \frac{(\text{Initial weight} - \text{Final weight})}{\text{Initial weight}} \times 100 \tag{1}$$

Shelf-life of strawberries was determined by observing the shriveling which was due to physiological loss in mass. Five per cent loss in mass was considered as an index of end of shelf-life.

Fruit internal temperature (°C)

Fruit internal temperature was measured with the help of probe thermometer by inserting its needle inside the fruit.

Disease (%)

Disease (%) was determined by counting the diseased fruit out of total fruits and expressed as percentage.

Biochemical quality parameters

Chemicals and reagents

All chemicals and reagents were of analytical grade. Sodium hydro oxide (NaOH), oxalic acid, 2, 6-dichlorophenolindophenol dye, methanol, hydrochloric acid (HCl, acetone, sodium bicarbonate (Na_2CO_3) and gallic acid 1-hydrate were purchased from Sigma Aldrich. 1,1-diphenyl-2-picryl-hydrazyl (DPPH) was purchased from Alfa Aesar.

pH

pH was determined after each removal. Strawberry juice was extracted after mashing it in pastel and mortar. The pH of the juice was measured with digital pH meter (Milwaukee pH55).

Electrical Conductivity (EC) (S/m)

The EC was calculated after extracting the juice of strawberries. The Lovibond Senso Direct Con 110 Digital EC meter was used for its determination. Taking the juice in a beaker and dipping the electrode of EC meter, the reading was noted down when it appears on the screen of the meter.

Total soluble solids (°Brix)

Strawberries juice was extracted and analyzed by using digital refractometer (ATAGO PAL-1). Two drops of clear juice was placed on surface of prism and reading was taken. Data was taken at each removal of both lots and expressed in ºBrix.

Titratable acidity (%)

Strawberry juice titratable acidity (%) was determined by following the method described by Hortwitz (1960). Samples were titrated against 0.1 N NaOH using two to three drops of phenolphthalein as an indicator, and the results were expressed in percentage.

Ascorbic acid (mg100mL^{-1})

Juice ascorbic acid was determined by following the method reported by Ruck (1969) with some modifications. 2, 6-dichlorophenolindophenol dye solution was used to titrate 5ml of aliquot (containing 10 mL of juice and 90 mL of 0.4% oxalic acid solution).

Total phenol contents (µg ml^{-1})

Total phenolic contents were determined by Folin-Ciocalteu (FC) method as described by Ainsworth and Gillespie (2007) with some modifications. Take 0.2 g of pulp of sample and homogenize it in pestle and mortar by adding 8 ml of methanol: acetone: HCl solution (90:8:2). Centrifuge the samples (13000 g for 3 min at room temperature) and collect the supernatant in a fresh falcon tubes. Add 100µl of sample supernatant and blank (methanol: acetone: HCl) in a fresh eppendrof tube add 200µl 10% FC reagent and vortex thoroughly for few seconds. Add 800µl 700mM Na_2CO_3 in each tube and again vortex for few seconds and incubate tubes at room temperature for 1h. Transfer one ml sample and one ml of distilled water in cuvette and read the absorbance at 765 nm.

Antioxidants (IC$_{50}$ µg ml^{-1})

Antioxidant activity was determined by the method of Noor et al. (2014) with some modifications. 50ul extract was added to 5 ml 0.004% (4mg/100ml) of methanol solution of DPPH. After 30 minutes in incubation period at room temperature absorbance was measured at 517 nm. Then same procedure was repeated for 100 µl extract and 150 µl extract. Inhibition (%) was calculated as follows (2):

$$\text{Inhibition (\%)} = \frac{A_{control} - A_{sample}}{A_{control}} \times 100 \qquad (2)$$

Where $A_{control}$ was the absorbance of DPPH and A_{sample} was the absorbance of free radical DPPH after adding a sample extract. Inhibition concentration$_{50}$ (IC_{50}) values represent the concentration of sample, which was necessary to scavenge 50% of DPPH free radicals. The higher the antioxidants activity, the lower will be the IC_{50} value.

RESULTS

Temperature (°C) and relative humidity (%)

Maximum temperature in ZECC was 23.3°C and at ambient conditions in laboratory was 26.4°C. Relative humidity in ZECC was high (86%) as compared to laboratory (43%). Temperature difference of 3.41°C and relative humidity difference of 38.22% was found between ZECC and ambient conditions during the day (Fig. 2).

Physical quality parameters

Mass loss (%) and shelf-life (days)

Effect of treatment (Table 7), storage conditions and treatment × storage conditions (Table 1) had statistically significant influence on mass loss (%) of strawberry fruit while, all other factors and their interactions had statistically no significant (data not given) influence. Mass loss was lower (1.59%) in ZECC and higher at ambient conditions (6.46%) (Table 1). Control had maximum mass loss (9.11%) whereas polyethylene packed fruit had minimum mass loss (1%) after storage (Table 7). Five percent mass loss was considered as end of shelf-life. Shelf-life of strawberry was less at ambient conditions (less than 3 days) and higher (more than 3 days) in ZECC (Table 1). Interaction of storage conditions and treatment revealed that shelf-life at ambient conditions in all treatments was lower than ZECC (Table 1). Control had less than three day's shelf-life while polyethylene packed fruit had more than three days shelf-life (Table 7).

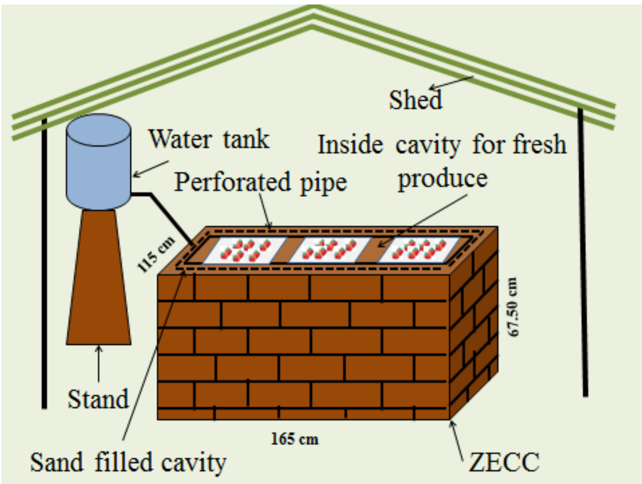

Fig. 1. Schematic view of zero energy cool chamber

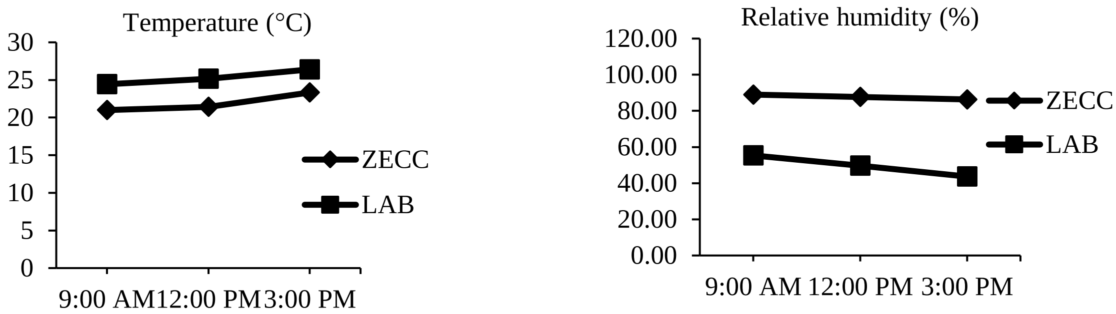

Fig. 2. Temperature (°C) and relative humidity (%) during the study

Table 1. Interaction of storage conditions and treatment on mass loss (%) and shelf-life, internal temperature (°C) and disease (%) of strawberry fruit

Storage conditions	Control	Polyethylene	Perforated Polyethylene	Mean
	Mass loss (%) and shelf-life (days)†			
ZECC	2.95b (> 3 days)	0.68c (> 3 days)	1.15c (> 3 days)	1.59b (> 3 days)
Ambient conditions	15.26a (< 3 days)	1.79bc (> 3 days)	2.32bc (> 3 days)	6.46a (< 3 days)
p-value	0.000			0.000
	Fruit internal temperature (°C)			
ZECC	22.17	22.29	22.25	22.24b
Ambient conditions	22.93	23.09	23.09	23.04a
p-value	0.9471			0.000
	Disease (%)			
ZECC	4.11	0	4.11	2.74
Ambient conditions	1.33	4.11	2.78	2.74
p-value	0.3629			1.000

†Shelf-life was determined on mass loss basis. Five percent loss in mass was considered end of shelf-life. ZECC: Zero energy cool chamber

Table 2. Interaction of storage conditions and treatment on pH, EC, TSS and TA (%) of strawberry juice

Storage conditions	Control	Polyethylene	Perforated Polyethylene	Mean
	pH†			
ZECC	3.91	3.92	3.96	3.93
Ambient conditions	3.94	3.97	3.97	3.96
p-value	0.7931			0.1528
	EC (S/m)			
ZECC	3.71	3.48	3.55	3.58
Ambient conditions	3.77	3.56	3.59	3.64
p-value	0.9648			0.3567
	TSS (°Brix)			
ZECC	6.35	5.82	5.81	6
Ambient conditions	6.03	5.96	5.88	5.96
p-value	0.5401			0.8217
	TA (%)			
ZECC	4.06	4.42	4.02	4.17
Ambient conditions	4.08	3.96	3.97	4.01
p-value	0.7780			0.5974

†EC: Electrical conductivity; TA: Titratable acidity; TSS: Total soluble solids; ZECC: Zero energy cool chamber

Fruit internal temperature (°C)

Fruit internal temperature was significantly lowered in ZECC (22.24 °C) and higher at ambient conditions in laboratory (23.04 °C) while other factors and their interactions had statistically non-significant effect on internal temperature of fruit (Table 1, 4 and 7).

Disease (%)

Storage duration and treatment had no significant influence on disease (%) (Table 1 and 7). Storage duration had significant influenc on disease (%). Maximum disease (8.22%) was recorded at the end of experiment (Table 4). All interaction effects had no significant influence on disease (%) during the study (Table 1, 4 and 7).

Biochemical quality parameters

pH

Storage duration had significant influenc on pH of strawberry juice. The pH reduced during storage duration (Table 5). All factors and their interactions had statistically no significant effect on pH of strawberry juice (Table 2, 5 and 8).

Table 3. Interaction of storage conditions and treatment on ascorbic acid (mg 100mL^{-1}), total phenols (µg mL^{-1}) and antioxidants (IC$_{50}$ µg mL^{-1}) of strawberry juice

Storage conditions	Control	Polyethylene	Perforated Polyethylene	Mean
	Ascorbic acid (mg 100mL^{-1})			
ZECC	124.82	117.94	123.23	122
Ambient conditions	113.71	113.18	139.10	122
p-value	0.2225			1.000
	Total phenols (µg mL^{-1})			
ZECC	0.69	0.72	0.72	0.72
Ambient conditions	0.72	0.75	0.71	0.71
p-value	0.7793			0.6182
	Antioxidants (IC$_{50}$ µg mL^{-1})†			
ZECC	0.73	0.61	0.89	0.74
Ambient conditions	0.91	0.47	0.59	0.65
p-value	0.8096			0.7721

†Antioxidants are represented as IC50 value. Larger IC50 value means less antioxidant activity. IC: Inhibition concentration

Table 4. Effect of three-way interaction on mass loss (%), internal temperature (°C) and disease (%) of strawberry fruit

Conditions	Treatments	Mass loss (%)		Fruit internal Temperature (°C)			Disease (%)		
		Storage duration		Storage duration			Storage duration		
		Mid	End	At harvest	Mid	End	At harvest	Mid	End
ZECC	Control	2.51	3.40	22.24	21.83	22.44	0	0	12.33
	Polyethylene	0.51	0.85	22.24	22.07	22.56	0	0	0
	Perforated polyethylene	1.10	1.20	22.24	22.07	22.44	0	0	12.33
Ambient conditions	Control	14.33	16.20	22.24	23.17	23.39	0	0	4.00
	Polyethylene	2.26	1.32	22.24	23.61	23.44	0	0	12.33
	Perforated polyethylene	1.49	3.14	22.24	23.41	23.65	0	0	8.33
Mean storage duration		3.70	4.35	22.24c	22.69b	22.99a	0b	0b	8.22a
P-value storage condition × treatment × storage duration		0.1953		0.9494			0.3989		
P-value storage duration		0.465		0.000			0.0025		

Electrical conductivity (EC) (S/m)

Treatments had significant effect on EC of strawberry juice (Table 8) while other factors and their interactions had statistically no significant influence on juice EC (Table 2 and 5). Maximum EC (3.74 S/m) was found in control and minimum EC (3.52 S/m) was found in strawberries packed in polyethylene bags. The EC significantly increased during storage duration (Table 5).

Total soluble solids (TSS) (°Brix)

The TSS significantly decreased during storage duration (Table 5). All factors and their interactions had statistically no significant effect on TSS of strawberry juice (Table 2, 5 and 8).

Titratable acidity (%)

The titratable acidity (%) of strawberry juice significantly decreased during storage duration (Table 6). All factors and their interactions had statistically no significant effect on titratable acidity (%) of strawberry juice (Table 2, 6 and 8).

Ascorbic acid (mg100mL^{-1})

Ascorbic acid concentrations significantly declined during storage duration (Table 6) irrespective of treatment and storage conditions. Ascorbic acid concentration of the fruit remained statistically similar under different storage conditions and interaction of storage conditions and treatment (Table 3), with interaction of storage conditions, treatment and storage duration (Table 6) and with various treatments (Table 8).

Total Phenols (µg mL^{-1})

Total phenols of the fruit were not affected by storage conditions and interaction of storage conditions and treatment (Table 3), storage duration, interaction of storage conditions, treatment and storage duration (Table 6) and with various treatments (Table 8).

Antioxidants concentrations (IC$_{50}$ µg mL^{-1})

Antioxidant concentrations of the fruit remained statistically at par under different storage conditions and interaction of storage conditions and treatment (Table 3) and with various treatments (Table 8).

Table 5. Effect of three-way interaction on pH, electrical conductivity (S/m) and TSS (°Brix) of strawberry juice

Conditions	Treatments	pH			Electrical conductivity (S/m)			TSS (°Brix)		
		Storage duration			Storage duration			Storage duration		
		At harvest	Mid	End	At harvest	Mid	End	At harvest	Mid	End
ZECC	Control	4	3.80	3.93	3.32	3.91	3.90	6.77	6.37	5.93
	Polyethylene	4	3.90	3.87	3.32	3.42	3.70	6.77	5.27	5.43
	Perforated polyethylene	4	3.97	3.90	3.32	3.73	3.60	6.77	5.70	4.97
Ambient conditions	Control	4	3.93	3.90	3.32	3.79	4.20	6.77	5.37	5.97
	Polyethylene	4	4	3.90	3.32	3.64	3.72	6.77	5.93	5.17
	Perforated polyethylene	4	3.97	3.93	3.32	3.54	3.91	6.77	5.57	5.30
Mean storage duration		4a	3.93b	3.91b	3.32c	3.67b	3.84a	6.77a	5.70b	5.46b
P-value storage condition × treatment × storage duration			0.5753			0.4099			0.3997	
P-value storage duration			0.0014			0.000			0.000	

Table 6. Effect of three-way interaction on TA (%), ascorbic acid (AA) (mg 100mL^{-1}), and total phenols (µg mL^{-1}) of strawberry juice

Conditions	Treatments	TA (%)			Ascorbic acid (AA) (mg 100mL^{-1})			Total phenols (µg mL^{-1})	
		Storage duration			Storage duration			Storage duration	
		At harvest	Mid	End	At harvest	Mid	End	Mid	End
ZECC	Control	6.18	3.73	2.26	142.80	103.13	128.52	0.74	0.65
	Polyethylene	6.18	4.74	2.32	142.80	109.48	101.55	0.78	0.66
	Perforated polyethylene	6.18	4.33	1.56	142.80	123.76	103.13	0.76	0.68
Ambient conditions	Control	6.18	4.54	1.54	142.80	96.79	101.55	0.76	0.68
	Polyethylene	6.18	4.22	1.47	142.80	103.13	93.61	0.67	0.83
	Perforated polyethylene	6.18	4.20	1.54	142.80	152.32	122.17	0.65	0.77
Mean storage duration		6.18a	4.29b	1.78c	143.80a	114.77b	108.42b	0.72	0.71
P-value storage condition × treatment × storage duration			0.8834			0.7703		0.1210	
P-value storage duration			0.000			0.0002		0.6053	

Table 7. Treatment effect on fruit physical quality parameters of strawberry

Treatment	Mass loss (%)	Shelf-life (days)†	Fruit internal temperature (°C)	Disease (%)
Control	9.11a	< 3 days	72.59	2.72
Polyethylene	1.24b	> 3 days	72.85	2.06
Perforated polyethylene	1.73b	> 3 days	72.82	3.44
P-value		*	0.5081	0.8591

†Shelf-life was determined on mass loss basis. Five percent loss in mass was considered end of shelf-life.

Table 8. Treatment effect on fruit biochemical quality parameters of strawberry

Treatment	EC (S/m)	TSS (°Brix)	pH	Acidity (%)	Ascorbic acid (mg 100mL^{-1})	Total phenol (µg mL^{-1})	Antioxidants (IC_{50} µg mL^{-1})
Control	3.74a	6.19	3.93	4.07	119.26	0.71	0.83
Polyethylene	3.52b	5.89	3.94	4.19	115.56	0.73	0.54
Perforated polyethylene	3.57b	5.84	3.96	4.00	131.16	0.71	0.74
P-value	0.0181	0.2360	0.4155	0.8740	0.1373	0.7377	0.7330

DISCUSSION

The study showed a difference of temperature and relative humidity between ZECC and ambient conditions (Fig. 1). This might be due to evaporation of water applied to the sand. Water absorbs heat from its surroundings to evaporate resulted in reduction of temperature inside ZECC. As water evaporates it raises the relative humidity and at the same time reduces temperature of the surroundings (Lal Basediya et al., 2013). In New Dehli, Verma (2014) reported a 15-18°C fall in temperature and more than 90% rise in relative humidity inside cool chamber. Similarly, Burbade et al. (2017) found a reduction of 8-9°C temperature and an increment of 10% relative humidity in ZECC as compared to ambient conditions.

Mass loss was lower in ZECC and higher at ambient conditions. Mass loss is an important factor for determining quality of fresh produce (Nunes & Emond, 2007). It depends upon rate of respiration and transpiration (moisture loss) of the commodity. Both of these factors are influenced by temperature and relative humidity. Moisture loss from the fresh produce depends upon vapor pressure deficit in the surroundings (Aked & Jongen, 2002). In ZECC, due to evaporative cooling, humidity increased and temperature decreased. The lower temperature and high relative humidity inside the ZECC might reduce respiration and transpiration from fresh produce. Respiration causes mass loss because a molecule of water is produced with a loss of each carbon atom (Sharma et al., 2018). This could be the reason for less mass loss in produce stored in ZECC as compared to laboratory where temperature and humidity were comparatively high. Similar results were also reported by Singh et al. (2010) (Indian gooseberry); Rayaguru et al. (2010) (tomato, potato, brinjal, banana and leafy vegetables), Islam and Morimoto (2012) (tomato and eggplant) and Islam et al. (2013) (tomato). In both ZECC and at ambient conditions mass loss was higher in control and lower in strawberries packed in polyethylene bags. This could be due to the fact that packaging creates an atmosphere of low oxygen and high carbon dioxide around the produce which might reduce the respiration rate and inhibit senescence of fresh produce and hence reduced mass loss. Moreover packaging also increased moisture and reduced vapour pressure deficit around the produce which resulted in reduced transpiration from fresh produce and hence reduced mass loss. The results are in conformity with the findings of Nunes et al. (1998) who reported that more mass loss was found when strawberries were unwrapped and when storage temperature and storage time increased.

Electrical conductivity increased with increase in storage duration. Electrical conductivity can successfully be used as a physical maturity index, and it is a appropriate index of storage quality (Feng et al., 2005). High conductivity is indicative of leakage of intracellular ions and, therefore, damage to membranes (Ade-Omowaye et al., 2003). According to Sarang et al. (2008) electrical conductivity might increase due to increase in senescence of fruit tissue. The electrical conductivity (EC) of the fruit tissue constantly increased after harvest, suggesting a gradual loss of cell membrane integrity (Ahmed et al., 2010). Similarly, increased in electrical conductivity with increased in storage duration was also reported by Ahmed et al. (2010) in avocado. Electrical conductivity of strawberry juice was significantly higher in control (unpacked) as compared to polyethylene and perforated polyethylene packed fruits. Similarly, Sharma et al. (2018) reported reduced electrolyte leakage in basil leaves packed in low density polyethylene bags as compared to control. The increased in electrical conductivity in control unpacked fruit might be due to more availability of oxygen for respiration which resulted in more senescence as compared to polyethylene packed fruits which had limited oxygen availability for respiration and hence reduced senescence and electrical conductivity.

Irrespective of treatment and storage duration titratable acidity, pH, ascorbic acid and TSS decreased with increased in storage duration. Similar results for reduction in titratable acidity and ascorbic acid were reported by Singh et al. (2017) in pear during storage. Storage conditions had no significant influence on biochemical quality attributes of strawberry during storage. Likewise Shin et al. (2007) also reported that temperature and relative humidity had no significant influence on pH and acidity of strawberry during storage.

Fruit packed in polyethylene bags and kept in ZECC had lowest mass loss and EC of juice and can give maximum return to the grower. Other physicochemical parameters remained statistically similar in both ZECC and ambient conditions.

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Conflict of interest

The authors declare that they have no conflict of interest.

REFERENCES

Ade-Omowaye, B. I. O., Taiwo, K. A., Eshtiaghi, N. M., Angersbach, A., & Knorr, D. (2003). Comparative evaluation of the effects of pulsed electric field and freezing on cell membrane permeabilisation and mass transfer during dehydration of red bell peppers. *Innovative Food Science & Emerging Technologies*, *4*(2), 177-188.

Ahmed, D. M., Yousef, A. R., & Hassan, H. S. A. (2010). Relationship between electrical conductivity, softening and color of *Fuerte avocado* fruits during ripening. *Agriculture and Biology Journal of North America*, *1*(5), 878-885.

Ainsworth, E. A., & Gillespie, K. M. (2007). Estimation of total phenolic content and other oxidation substrates in plant tissues using Folin–Ciocalteu reagent. *Nature Protocols*, *2*(4), 875. https://doi.org/10.1038/nprot.2007.102.

Aked, J., & Jongen, W. (2002). Maintaining the postharvest quality of fruits and vegetables. In W. Jongen (Ed.). *Fruit and Vegetable Processing: Improving Quality* (pp. 119–149). Cambridge, UK: Woodhead Publishing Ltd.

Azene, M., Workneh, T. S., & Woldetsadik, K. (2014). Effect of packaging materials and storage environment on postharvest quality of papaya fruit. *Journal of Food Science Technology*, *51*(6), 1041–1055. https://doi.org/10.1007/s13197-011-0607-6.

Burbade, R. G., Sengar, S. H., & Sonawane, A. V. (2017). Performance evaluation of developed evaporative cooling storage structure for tomato. *International Journal of Science, Environment and Technology*, *6*(5), 2975-2982.

Burdon, J. N. (2001). Postharvest handling of tropical and subtropical fruit for export. In: (ed Mitra, S.) *Postharvest Physiology and Storage of Tropical and Subtropical Fruits*. Faculty of Horticulture, CAB International, West Bengal, India, 1-19.

Feng, G., Yang, H., & Li, Y. (2005). Kinetics of relative electrical conductivity and correlation with gas composition in modified atmosphere packaged bayberries (*Myrica rubra* Siebold and Zuccarini). *LWT-Food Science and Technology*, *38*(3), 249-254.

Hening, Y. S. & Gilbert, S. G. (1975). Computer analysis of the variables affecting respiration and quality of produce packaged in polymeric films. *Journal of Food Science*, *40*, 1033- 1035. https://doi.org/10.1111/j.1365-2621.1975.tb02261.x.

Hortwitz, W. 1960. *Official and Tentative Methods of Analyssis*. Association of the Official Agriculture Chemist, Washington DC, USA. pp, 314-320.

Islam, M. P., & Morimoto, T. (2012). Zero energy cool chamber for extending the shelf-life of tomato and eggplant. *Japan Agricultural Research Quarterly*, *46*(3), 257-267. https://doi.org/10.6090/jarq.46.257.

Islam, M. P., Morimoto, T., & Hatou, K. (2013). Dynamic optimization of inside temperature of Zero Energy Cool Chamber for storing fruits and vegetables using neural networks and genetic algorithms. *Computers and Electronics in Agriculture, 95*, 98-107. https://doi.org/10.1016/j.compag.2013.04.008.

Jha, S. N., & Kudos, S. K. (2006). Determination of physical properties of pads for maximizing cooling in evaporative cooled store. *Journal of Agricultural Engineering Research, 43*(4), 92-97.

Jin, P., Wang, S. Y., Wang, C. Y., & Zheng, Y. (2011). Effect of cultural system and storage temperature on antioxidant capacity and phenolic compounds in strawberries. *Food Chemistry, 124*(1), 262-270.

Kebede, E. (1991). Processing of horticultural produce in Ethiopia. *Acta Horticulturae, 270*, 298-301. https://doi.org/10.17660/ActaHortic.1991.270.36.

Lal Basediya, A., Samuel, D. V. K., & Beera, V. (2013). Evaporative cooling system for storage of fruits and vegetables-a review. *Journal of Food Science Technology, 50*(3), 429-442. https://doi.org/10.1007/s13197-011-0311-6.

Kanak, L., & Sanjay, S. (2013). Cost effective on farm storage: zero energy cool chamber for the farmers of Gujarat. *Asian Journal of Horticulture, 8*(1), 50-53.

Memon, N.A. (2014). Strawberry widely consumed throughout world. *Pakistan Food Journal*, 38-40.

Murtaza, A. (2014). Strawberry a delicious fruit. http://www.foodjournal.pk/2014/July-September-2014/PDF-Jan-March-2014/Anjuman-Strawberry.pdf.

Noor, N., Sarfraz R. A., Ali. S., & Shahid, M. (2014). Antitumour and antioxidant potential of someselected Pakistani honeys. *Food Chemistry, 143*, 362-366. https://doi.org/10.1016/j.foodchem.2013.07.084.

Nunes, M. C. N., & Emond, J. P. (2007). Relationship between weight loss and visual quality of fruits and vegetables. In *Proceedings of the Florida State Horticultural Society, 120*, 235-245.

Nunes, M. C. N., Brecht, J. K., Morais, A., & Sargent, S. A. (1998). Controlling temperature and water loss to maintain ascorbic acid levels in strawberries during postharvest handling. *Journal of Food Science, 63*, 1033-1036. https://doi.org/10.1111/j.1365-2621.1998.tb15848.x.

Odesola, I. F., & Onyebuchi, O. (2009). A review of porous evaporative cooling for the preservation of fruits and vegetables. *The Pacific Journal of Science and Technology, 10*(2), 935-941.

Pal, R. K., & Roy, S. K. (1988). Zero-energy cool chamber for maintaining post-harvest quality of carrot (*Daucus carota* var sativa). *Indian Journal of Agricultural Sciences, 58*(9), 665-667.

Panda, A. K., Goyal, R. K., Godara, A. K., & Sharma, V. K. (2016). Effect of packaging materials on the shelf-life of strawberry cv. Sweet Charlie under room temperature storage. *Journal of Applied and Natural Science, 8*(3), 1290-1294. https://doi.org/10.31018/jans.v8i3.955.

Patil, S. B., Raut, V. U., Gadekar, A. K., & Patil, S. M. (2011). Effect of packaging and cushioning materials on shelf life of custard apple fruits under different storage conditions. *Asian Journal of Horticulture, 6*(1), 264-268.

Prasad, R., Ram, R. B., Kumar, V., & Rajvanshi, S. K. (2015). Study on effect of different packaging materials on shelf life of banana (*Musa paradisiaca* L.) cv. Harichal under different conditions. *International Journal of Pure and Applied Bioscience, 3*(4), 132-141.

Rajwana, I. A., Razzaq, K., Hussain, S. B., Amin, M., Khan, A. S., & Malik, A. U. (2016). Strawberry cultivation in southern Punjab Pakistan. In *VIII International Strawberry Symposium, 1156*, 909-914.

Rayaguru, K., Khan, M. K. & Sahoo, N. R. (2010). Water use optimization in zero energy cool chambers for short term storage of fruits and vegetables in coastal area. *Journal of Food Science Technology, 47*(4), 437-441. https://doi.org/10.1007/s13197-010-0072-7.

Ruck, J. A. (1969). *Chemical methods for analysis of fruit and vegetables products.* Summerland Research Station, Department of Agriculture, Canada, pp. 27-30.

Sarang, S., Sastry, S. K., & Knipe, L. (2008). Electrical conductivity of fruits and meats during ohmic heating. *Journal of Food Engineering, 87*(3), 351-356.

Sharma, R., Bhatia, S., & Kaur, P. (2018). Influence of packaging and storage conditions on biochemical quality and enzymatic activity in relation to shelf life enhancement of fresh basil leaf. *Journal of Food Science and Technology, 55*(8), 3199-3211.

Shin, Y., Liu, R. H., Nock, J. F., Holliday, D., & Watkins, C. B. (2007). Temperature and relative humidity effects on quality, total ascorbic acid, phenolics and flavonoid concentrations, and antioxidant activity of strawberry. *Postharvest Biology and Technology*, *45*(3), 349- 357. https://doi.org/10.1016/j.postharvbio.2007.03.007.

Singh, S., Singh, A. K., Joshi, H. K., Bagle, B. G., & More, T. A. (2010). Effect of zero energy cool chamber and post-harvest treatments on shelf-life of fruits under semi-arid environment of western India. Part 2. Indian gooseberry fruits. *Journal of Food Science Technology*, *47*(4), 450-453.

Singh, V., Dudi, O. P., & Goyal, R. K. (2017). Effect of different packaging materials on post-harvest quality parameters of pear under zero energy chamber storage condition. *International Journal of Current Microbiology and Applied Sciences*, *6*(9), 1167-1177. https://doi.org/10.20546/ijcmas.2017.609.141.

Singh, V., Dudi, O. P., Sandooja, J. K., & Goyal, R. K. (2018). Packaging in polyethylene bags and storage in zero energy cool chambers improves storage life of pear fruits under subtropics. *International Journal of Chemical Studies*, *6*(2), 1657-1663.

Verma, A. (2014). Pre-cooling of fresh vegetables in low cost zero energy cool chamber at farmer's field. *Asian Journal of Horticulture*, *9*(1), 262-264.

Wolde, B. (1991). Horticulture marketing systems in Ethiopia. *Acta Horticulture*, *270,* 21-31.

Xuan, Y. M., Xiao, F., Niu, X. F., Huang, X., & Wang, S. W. (2012). Research and application of evaporative cooling in China: A review (I) - Research. *Renewable and Sustainable Energy Reviews*, *16*(5), 3535–3546. doi:10.1016/j.rser.2012.01.052.

Yang, D., Xie, H., Jiang, Y., & Wei, X. (2016). Phenolics from strawberry cv. Falandi and their antioxidant and α-glucosidase inhibitory activities. *Food Chemistry*, *194*, 857-863. doi: 10.1016/j.foodchem.2015.08.091.