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Effects of Packaging and Low Temperature on Shelf Life and Quality of Litchi

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Abstract
Litchi is a non-climacteric fruit and it deteriorates very fast after harvest. Various technologies have been devised to minimize the post-harvest losses of Litchi; one of such technologies is the use of Polypropylene bag and low temperature. The objectives of the present study were to evaluate the effects of thickness of polypropylene bags and low temperature on the storage behavior of Litchi (*Litchi chinensis* Sonn, var. Bombai). The experiment consisted of two factors including temperature (T_1: Ambient temperature, T_2: 4ºC temperature); and Polypropylene bags (P_1: Control (unwrapped), P_2: 50 µm Polypropylene bag, P_3: 75 µm Polypropylene bag, P_4: 100 µm Polypropylene bag. The experiment was conducted in completely randomized design (CRD) with three replications. The postharvest treatments caused highly significant variation in the shelf life of Litchi. Among the treated and untreated fruits, 75 µm Polypropylene bags at low temperature (4 ºC) exhibited better storage performance. The fruits wrapped in 75 µm Polypropylene bag at 4 °C showed the longest shelf life (23.67 days) followed by 50 µm and 100 µm Polypropylene bags at 4 °C (23.33 days). The shortest shelf life was obtained in the untreated fruits (3 days). It may be concluded that keeping Litchi in 75 µm Polypropylene bag and stored in low temperature (4 ºC) is the best postharvest approach to extend Litchi shelf life without considerable negative effects on fruit quality. For short-term storage of Litchi fruits 75 µm Polypropylene bag at ambient temperature is recommended.

Keywords: Low temperature, Litchi, shelf life, polypropylene bags, postharvest.

Introduction

Litchi *(Litchi chinensis* Sonn.) is regarded as one of the kings of sub-tropical fruits and famous for its excellent quality such as juiciness, slightly sour-sweet taste, pleasant flavor and for attractive color. Litchi is a non-climacteric fruit (Wills *et al*. 2004) and it deteriorates very fast after harvest. The pericarp browning is considered the most important postharvest problem of Litchi. Browning that occurs during the first few days after harvest is usually caused by dehydration of the pericarp. Fruit start to brown once they loss a few percent of the harvested pericarp fresh weight (Jiang and Fu, 1999). The present

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work mainly focuses on pericarp browning reduction of Litchi and therefore, the biochemistry of browning needs to be clearly understood. The brilliant colors of mature Litchi fruits are largely due to a range of anthocyanins located in the mid to upper mesocarp (Underhill and Critchley, 1993). The anthocyanins are stable at pH below 3, but are converted to colorless chromenols in an acid reversible reaction, as the pH rises. Anthocyanins are also prone to enzymatic and non-enzymatic oxidations, often leading to the production of melanin by-products (Kaiser, 1994).

The expression of different attractive color in hydrated tissues seems to be related to the compartmentalization of the cells. The anthocyanins are located in the vacuole, which is expected to be highly acidic because of the proton gradient across the tonoplast that amongst other thing drives the accumulation of organic acids (Ratajczak and Wilkins, 2000). In addition, anthocyanin oxidative enzymes tend to be sequestered elsewhere. For example, polyphenol oxidase is found in chloroplasts or other plastids (Underhill and Critchley, 1995). Dehydration may act to disrupt the cell compartments, elevate the permeability of the membranes, raise the pH of the vacuole, and accelerate the oxidation of anthocyanins and other cell components. As a result, the distinctive Litchi pigments fade and a range of brown pigments appear. In this regard, Jiang and Fu (1999) found that the rate of water loss is correlated with membrane permeability, the rate of browning, polyphenol oxidase activity and tissue pH negatively correlate with anthocyanin content.

Other factors that also cause the fruit to brown include: mechanical stresses (tugging the pedicel at harvest, sliding the fruit down a rough picking bag, dropping fruit from short heights, and decay at transport time); microbial and insect attacks and extremes temperatures. In short, anything likely to accelerate cell breakdown is likely to increase fruit browning. So the objective of the study is to investigate suitable postharvest treatment to reduce pericarp browning and to extend shelf life of Litchi.

Materials and Methods

The experiments were carried out at the laboratories of the Departments of Horticulture, Plant Pathology and Biochemistry of Bangladesh Agricultural University, Mymensingh during the period from 15 May to 15 September, 2016. The Litchi cultivar, namely 'Bombai' was chosen as experimental materials for this investigation.

Experimental materials

Litchi cultivar 'Bombai' is the most important commercial cultivar of West Bengal, India. It is also cultivated commercially in Bangladesh. Fruits are mostly heart shaped and each fruit has another tiny underdeveloped fruit attached to the fruit as in case of the Chinese cultivar 'Hom Suiuchi'. Ripening commences from the last week of May. The color at maturity is indicated as yellow-green background with red tubercles. Average weight of fruit varies from 15-20 g. Fruit pulp is greyish white, soft, juicy, sweet to sour in taste and has pleasant flavor. The seeds are bigger in shape, 2.28 cm long, 1.58 cm in diameter, average weight 3.4 g, and elongated, smooth, shiny and light chocolate in color. The ratio of rind, pulp and seed by weight is 12.11:70.08:16.8. Ghosh *et al*. (1987) reported that the average fruit weight of Litchi is 190 g which consisted of 17.9% skin, 19.9% seed, 62.2% pulp on the basis of fruit weight. They also mentioned that the fruit pulp contained 17.7% total soluble solids, 0.42% acidity and 11.0% sugars.

Experimental treatments and design

In total 8 treatments were implemented in this experiment. The experiment consisted of two factors. Factor A: Temperature, T_1: Ambient temperature, T_2: 4 ºC temperature, Factor B: thickness of Polypropylene bag

(PP bags), P_1: Control (unwrapped), P_2: 50 µm PP bag, P_3: 75 µm PP bag, P_4: 100 µm PP bag. The two factor experiment was laid out in completely randomized design (CRD) with three replications having eight fruits. 36 cm × 24 cm size PP bags were used in this experiment.

Application of postharvest treatments

A total of 192 fruits of more or less similar shape and size and free of visible disease symptoms were randomly selected from the harvested fruits. Among eight fruits in each replication of each treatment four fruits were marked to investigate color, pericarp browning, total weight loss, disease incidence, disease severity, isolation and identification of causal pathogens, shelf life and the remaining four fruits were kept unmarked conditions for destructive sampling to examine moisture content, dry matter content, TSS, pulp to peel ratio, vitamin C and pulp pH.

Methods of studying parameters

Among eight fruits in each replication four fruits were used for destructive sampling at three days interval to investigate several parameters including moisture content, dry matter content, total soluble solids, pulp to peel ratio, vitamin C and pulp pH. The remaining four fruits were used to investigate pericarp browning, total weight loss and shelf life. The chemical parameters were estimated using the method of Ranganna (1979). Pericarp Browning was determined using numerical rating scale of 1-5, where, 1 = no browning, 2 = 1-<25% browning, 3 = 25-<50% browning, 4 = 50-<75% browning and 5 = 75-100% browning. Pulp to peel ratio was determined at 3^{rd}, 6^{th} and the 9^{th} day of storage and electric balance was used for determining weight. Weight loss of fruit was estimated during storage by using the following formula:

Weight loss (%) = $\frac{IW - FW}{IW} \times 100$. Where, IW = Initial weight of fruits (g), FW = Final weight of fruits (g). Percent moisture content was calculated according to the following formula: Moisture content (%) = $\frac{IW - FW}{IW} \times 100$. Where, IW = Initial weight of pulp (g). FW= Final weight of oven dried pulp (g). Dry matter (%) = (100%-% moisture content)

Total soluble solid (TSS) content of Litchi pulp was estimated by using Abbe's Refractometer. A drop of Litchi juice squeezed from the fruit pulp was placed on the prism of the Refractometer. Then TSS was obtained from direct reading of the instrument. Temperature corrections were made by using temperature correction chart that accompanied the instrument.

The pH meter (Hanna) was standardized by using buffer solution of pH 7 and pH 4 when correction for temperature was also taken into consideration. On completion of calibration the electrode was washed twice with distilled water, rinsed with Litchi juice and dipped into the juice. The pH was recorded.

Vitamin C content (mg/100 g) = $\frac{T \times D \times V_1}{V_2 \times W} \times 100$. Where, T = Titre, D = Dye factor, V_1 = Volume made up, V_2 = Volume of extract, W = Weight of sample

Titratable acidity of Litchi pulp was determined according to the method mentioned by Rangana (1979). Standard NaOH solution (0.1N) and 1% phenolphthalein solution were used for the determination of titratable acidity.

Percent titratable acidity= $\frac{T \times N \times V_1 \times E}{V_2 \times W \times 1000} \times 100$. Where, T=Titre, N=Normality of NaOH, V_1=Volume made up, E= Equivalent weight of acid, V_2= Volume of extract, W= Weight of sample.

Disease incidence (%) = $\frac{\text{Number of infected fruits}}{\text{Total number of fruits under study}} \times 100$

Disease severity refers to the percentage diseased portion of infected fruit. The infected fruits of each replication of each treatment (varieties) were observed to determine percentage of infected fruit area and was measured based on eye estimation. The mean values regarding infected fruit area were calculated, presented and discussed.

Shelf life of Litchi fruits as influenced by different varieties was calculated by counting the days required to ripe fully as to retaining optimum marketing and eating qualities.

Statistical analysis

For the experiment, the collected data were statistically analyzed by Analysis of Variance (ANOVA) test. The means of different parameters were compared by least significant difference (LSD) as described by Gomez and Gomez (1984). For percentage data arcsine transformations were carried out to satisfy the assumption of ANOVA.

Results

A. Changes in physical characters

Various physical changes of Litchi fruits as influenced by postharvest treatments have been presented and discussed in the following.

Pericarp browning

Combined effect of low temperature and thickness of PP bags on pericarp browning of Litchi was statistically highly significant (Supplemental Table 1). All the fruits kept in ambient temperature and in the low temperature without PP bags (4º C) had the maximum browning score (5.00) at 10th day of storage. Litchi fruits wrapped in PP bags and kept in low temperature (4 ºC) showed the same performance at 10th days of storage and had a browning score of 2.33 (Table 1).

Table 1. Combined effect of temperature and thickness of Polypropylene (PP) bags on pericarp browning of Litchi

Treatment combination	Pericarp browning at different days after storage									
	1	2	3	4	5	6	7	8	9	10
T_1P_1	1	2.00	3.33	4.33	5.00	5.00	5.00	5.00	5.00	5.00
T_1P_2	1	1.67	2.00	3.33	3.67	4.00	4.33	4.33	5.00	5.00
T_1P_3	1	1.00	1.00	1.00	1.67	2.00	3.00	3.33	3.67	5.00
T_1P_4	1	2.00	2.33	3.00	4.67	4.33	4.00	4.33	5.00	5.00
T_2P_1	1	2.33	2.67	4.00	5.00	5.00	5.00	5.00	5.00	5.00
T_2P_2	1	1.00	1.00	1.00	1.00	1.33	1.33	1.67	2.00	2.33
T_2P_3	1	1.00	1.00	1.00	1.00	1.00	1.00	1.33	1.67	2.33
T_2P_4	1	1.00	1.00	1.00	1.33	1.33	1.67	2.00	2.00	2.33
$LSD_{0.05}$	-	0.182	0.205	0.197	0.251	0.251	0.310	0.314	0.342	0.305
$LSD_{0.01}$	-	0.250	0.282	0.272	0.346	0.346	0.427	0.433	0.471	0.420
Level of significance	-	**	**	**	**	**	**	**	**	**

** = Significant at 1% level of probability, * = Significant at 5% level of probability, NS = Not significant

(T_1 = ambient temperature, T_2 = 4^0C temperature, P_1: Control (unwrapped), P_2: Fruits wrapped in 50µ PP bag, P_3: Fruits wrapped in 75µ PP bag, P_4: Fruits wrapped in 100µ PP bag)

Numerical browning scale: 1= no browning, 2=1-<25% brown, 3=25-<50% brown, 4=50-<75% brown, 5= 75-100% brown

Pulp to peel ratio

The combined effects of temperature and thickness of PP bags showed significant differences in respect of pulp to peel ratio during the entire storage period (Supplemental Table 2). The pulp to peel ratio showed an increasing rate up to the 6th day of storage period and decreased thereafter (Table 2). At the 3rd, 6th, and 9th days of storage period, the highest pulp to peel ratio was 7.31, 8.80, 7.08 respectively and all was observed at Litchis kept in control (unwrapped). At the 3rd day of storage the lowest pulp to peel ratio (4.45) was observed in Litchis kept in 4 ºC. At the 6th day of storage the lowest pulp to peel ratio (4.56) was observed in Litchis wrapped in 100 µm thickness of PP bag at ambient temperature. At the 9th day of storage, the lowest pulp to peel ratio (4.38) was observed in Litchis kept in 4 ºC.

Total weight loss

Highly significant effect on percent weight loss of Litchi was observed due to different temperatures (Supplemental Table 3). Percent of weight loss of Litchi fruits gradually increased with the progress of storage duration. Significantly, the maximum (14.95%) weight loss occurred at ambient temperature and the minimum (7.48%) weight loss occurred at low temperature (4 ºC) at the 10th day of storage (Fig. 1). Mainly low temperature (4 ºC) showed the best performance in minimizing of weight loss.

Table 2. Combined effect of temperature and thickness of Polypropylene (PP) bags on pulp to peel ratio of Litchi

Treatment combination	Pulp to peel ratio at different days after storage		
	3	6	9
T_1P_1	7.31	8.80	7.08
T_1P_2	4.55	4.58	4.43
T_1P_3	4.54	4.56	4.41
T_1P_4	4.58	4.60	4.39
T_2P_1	4.45	4.72	4.38
T_2P_2	4.49	4.85	4.54
T_2P_3	4.52	4.96	4.69
T_2P_4	4.46	4.78	4.52
$LSD_{0.05}$	0.190	0.268	0.182
$LSD_{0.01}$	0.261	0.369	0.250
Level of significance	**	**	**

** = Significant at 1% level of probability, * = Significant at 5% level of probability, NS = Not significant
T_1 = Ambient temperature,T_2 = 4^0C temperature
P_1: Control (unwrapped)
P_2: Fruits wrapped in 50µ PP bag
P_3: Fruits wrapped in 75µ PP bag
P_4: Fruits wrapped in 100µ PP bag

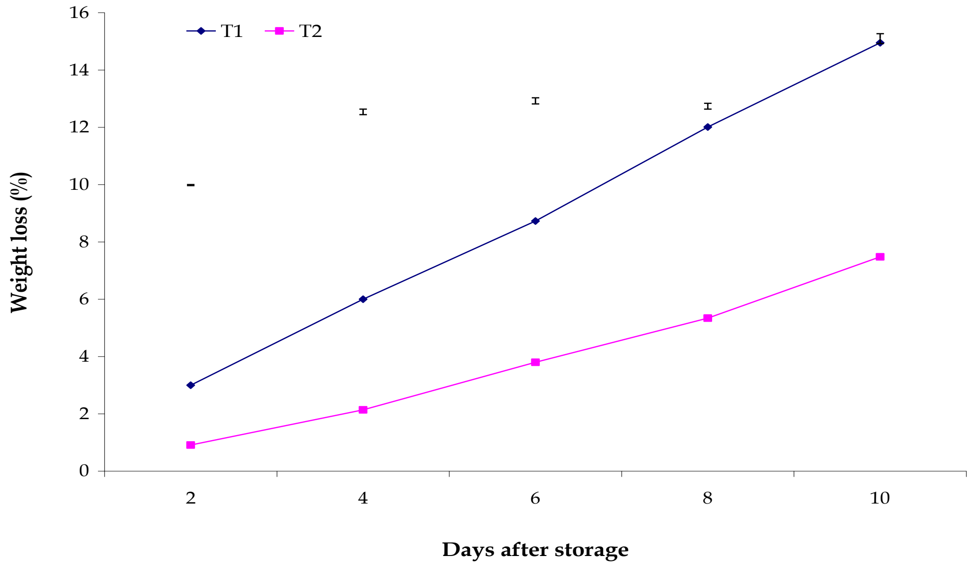

Fig. 1. Main effect of temperature on total weight loss of Litchi (T_1 = Ambient temperature, T_2 = 4^0C temperature)

The effect of thickness of PP bags was statistically significant to influence weight loss of Litchi during storage (Supplemental Table 3). At 10 days of storage, the highest rate of weight loss (23.68%) was found in control (Litchi left untreated) followed by in Litchis wrapped in 100 µm thickness of PP bag and the lowest rate (5.14%) was found at Litchis wrapped in 75 µm thickness of PP bags (Fig. 2).

The combined effect of temperature and thickness of PP bags on total weight loss of Litchi was statistically significant (Supplemental Table 3). At all the treatments the percentage of weight loss was increased gradually day by day. At 2nd, 4th, 6th, 8th, and 10th day the highest percentage of weight loss were 6.77%, 16.25%, 21.70%, 27.50% and 33.15% respectively and all of these weight losses were occurred in control (untreated) Litchis. At 2nd, 4th, 6th, and 10th day the lowest percentages of weight losses were 0.51%, 1.48%, 2.23% and 4.89% respectively and these were observed in Litchis wrapped in 75 µm thickness of PP bag and kept in 4 ºC temperature(T_2P_3) in Table 3. At the 8th day of storage the lowest percentage of weight loss was 3.40% and it was observed in Litchis wrapped in 50 µm PP bag and kept in 4 ºC temperature (T_2P_2).

Moisture content

The combined effects of thickness of PP bags and low temperature (4 ºC) were statistically significant to influence moisture content of Litchi fruits at different days after storage (Supplemental Table 4). The highest moisture content (83.85%) was observed in Litchis wrapped in 75 µm thickness of PP bag and kept in low temperature (4 ºC) followed by moisture content (83.62%) was observed in 50 µm thickness of PP bags at low temperature (4 ºC) at 3rd day of storage (Table 4). The lowest moisture content (76.43%) was observed at control (untreated) fruits followed by Litchis wrapped in 100 µm thickness of PP bag and kept in ambient temperature at 9th day of storage (Table 4).

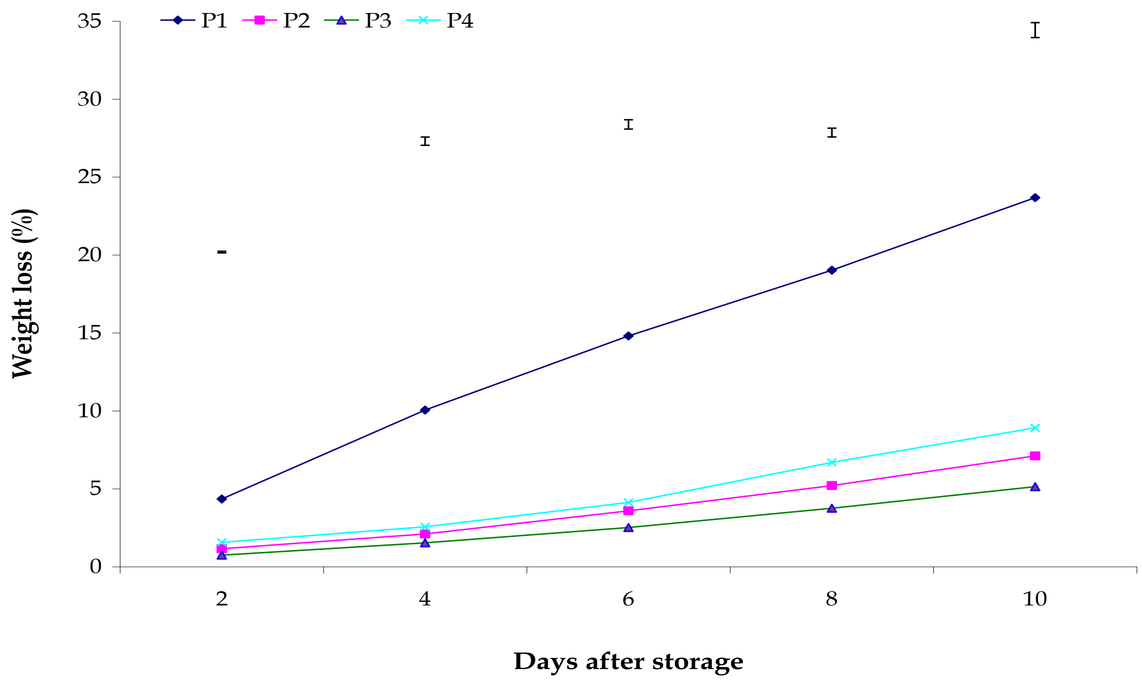

Fig. 2. Main effect of thickness of Polypropylene (PP) bags on total weight loss of Litchi
Where, P_1: Control (unwrapped), P_2: Fruits wrapped in 50µ PP bag, P_3: Fruits wrapped in 75µ PP bag, P_4: Fruits wrapped in 100µ PP bag

Table 3. Combined effect of temperature and thickness of Polypropylene (PP) bags on total weight loss of Litchi

Treatment combination	Total weight loss (%) at different days after storage (DAS)				
	2	4	6	8	10
T_1P_1	6.77	16.25	21.70	27.50	33.15
T_1P_2	1.74	2.63	4.72	7.02	9.16
T_1P_3	0.98	1.60	2.81	3.76	5.38
T_1P_4	2.51	3.51	5.67	9.74	12.10
T_2P_1	1.92	3.87	7.92	10.56	14.20
T_2P_2	0.57	1.58	2.46	3.40	5.08
T_2P_3	0.51	1.48	2.23	3.75	4.89
T_2P_4	0.63	1.62	2.59	3.66	5.73
$LSD_{0.05}$	0.245	1.228	1.376	1.305	2.211
$LSD_{0.01}$	0.337	1.691	1.896	1.797	3.047
Level of significance	**	**	**	**	**

** = Significant at 1% level of probability, * = Significant at 5% level of probability, NS = Not significant
T_1 = Ambient temperature, T_2 = 4^0C temperature
P_1: Control (unwrapped)
P_2: Fruits wrapped in 50µ PP bag
P_3: Fruits wrapped in 75µ PP bag
P_4: Fruits wrapped in 100µ PP bag

Table 4. Combined effect of temperature & thickness of Polypropylene (PP) bags on percent moisture content of Litchi

Treatment combination	Moisture content (%) at different days after storage		
	3	6	9
T_1P_1	81.01	78.65	76.43
T_1P_2	81.79	79.97	78.75
T_1P_3	82.42	80.17	79.80
T_1P_4	81.46	79.53	78.28
T_2P_1	82.23	80.93	79.00
T_2P_2	83.62	82.03	80.18
T_2P_3	83.85	82.20	80.76
T_2P_4	83.48	82.17	80.10
$LSD_{0.05}$	0.342	0.226	0.383
$LSD_{0.01}$	0.471	0.311	0.528
Level of significance	**	**	**

** = Significant at 1% level of probability, * = Significant at 5% level of probability, NS = Not significant
T_1 = Ambient temperature, T_2 = 4^0C temperature
P_1: Control (unwrapped)
P_2: Fruits wrapped in 50µ PP bag
P_3: Fruits wrapped in 75µ PP bag
P_4: Fruits wrapped in 100µ PP bag

Dry matter content

The combined effects of thickness of PP bags and low temperature (4 ºC) were statistically significant to influence dry matter content of Litchi at different days after storage (Supplemental Table 5). The highest dry matter content (23.57%) was observed at control (untreated) Litchis at 9th day of storage and the lowest percentage of dry matter content (16.15%) was observed in Litchis wrapped in 75 µm PP bag and kept in low temperature (4ºC) at 3rd day of storage (Table 5).

Table 5. Combined effect of temperature and thickness of Polypropylene (PP) bags on percentage of dry matter content of Litchi

Treatment combination	Dry matter content (%) at different days after storage		
	3	6	9
T_1P_1	18.99	21.35	23.57
T_1P_2	18.21	20.03	21.25
T_1P_3	17.58	19.83	20.20
T_1P_4	18.54	20.47	21.72
T_2P_1	17.77	19.07	21.00
T_2P_2	16.38	17.97	19.82
T_2P_3	16.15	17.80	19.24
T_2P_4	16.52	17.83	19.90
$LSD_{0.05}$	0.145	0.219	0.337
$LSD_{0.01}$	0.200	0.302	0.465
Level of significance	**	**	**

** = Significant at 1% level of probability, * = Significant at 5% level of probability, NS = Not significant
T_1 = Ambient temperature,T_2 = 4^0C temperature
P_1: Control (unwrapped)
P_2: Fruits wrapped in 50µ PP bag
P_3: Fruits wrapped in 75µ PP bag
P_4: Fruits wrapped in 100µ PP bag

B. Changes in bio-chemical characters

Bio-chemical changes, namely total soluble solid, pH of fruit pulp and vitamin C content were investigated in the present study. The results are presented and interpreted in the following.

Total soluble solids

The combined effects of thickness of PP bags and low temperature were statistically significant to influence total soluble solids contents of Litchi at different days after storage (Supplemental Table 6). The highest total soluble solid contents (21.20 ºBrix) was observed at control (untreated) Litchis at 6^{th} day of storage followed by Litchis kept in control at 9^{th} day after storage (20.40 ºBrix) and the lowest score of TSS (18.10 ºBrix) was observed in Litchis wrapped in PP bag of 75 µm thickness and kept in low temperature (4 ºC) followed by Litchis (18.20 ºBrix) wrapped in 50 µm PP bags and kept in low temperature (4 ºC) at 3^{rd} day of storage and Litchis (18.20 ºBrix) wrapped in 50 µm PP bags and kept in ambient temperature at 9^{th} day after storage (Table 6).

Table 6. Combined effect of temperature and thickness of Polypropylene (PP) bags on total soluble solids of Litchi

Treatment combination	Total soluble solids (TSS) at different days after storage		
	3	6	9
T_1P_1	19.60	21.20	20.40
T_1P_2	18.60	19.30	18.20
T_1P_3	18.50	19.20	18.30
T_1P_4	18.70	19.50	18.40
T_2P_1	18.40	19.10	19.30
T_2P_2	18.20	18.90	19.70
T_2P_3	18.10	18.80	19.50
T_2P_4	18.30	18.90	19.60
$LSD_{0.05}$	0.257	0.375	0.251
$LSD_{0.01}$	0.354	0.517	0.346
Level of significance	**	**	**

** = Significant at 1% level of probability, * = Significant at 5% level of probability, NS = Not significant
T_1 = Ambient temperature,T_2 = 4^0C temperature
P_1: Control (unwrapped)
P_2: Fruits wrapped in 50µ PP bag
P_3: Fruits wrapped in 75µ PP bag
P_4: Fruits wrapped in 100µ PP bag

pH of fruit pulp

The combined effect of temperature and thickness of PP bag on pH content of Litchi at different days of storage period was statistically non-significant (Supplemental Table 7). The highest pH of fruit pulp (4.14) was observed in Litchis wrapped in PP bag of 100 µm thickness and kept in ambient temperature (Table 7). The lowest pH of fruit pulp (3.62) was observed in Litchis wrapped in PP bag of 75 µm thickness and kept in low temperature (Table 7).

Vitamin C content

The combined effects of thickness of PP bag and low temperature (4 ºC) were statistically significant to influence vitamin C content of Litchi at different days after storage (Supplemental Table 8). The highest vitamin C content (35.73 mg/100g) was observed at Litchis kept in 4 °C temperature and wrapped in 75 µm PP bag and the lowest score of vitamin C content (21.34 mg/100g) was observed in control (Litchi left untreated) at 3rd and 9th day of storage respectively (Table 8).

Table 7. Combined effect of temperature and thickness of Polypropylene (PP) bags on pH of Litchi

Treatment combination	pH at different days after storage		
	3	6	9
T_1P_1	3.80	4.04	4.11
T_1P_2	3.71	3.95	4.10
T_1P_3	3.67	3.91	4.04
T_1P_4	3.78	3.98	4.14
T_2P_1	3.76	3.99	4.01
T_2P_2	3.66	3.91	4.04
T_2P_3	3.62	3.88	4.02
T_2P_4	3.74	3.95	4.11
$LSD_{0.05}$	0.077	0.055	0.055
$LSD_{0.01}$	0.107	0.075	0.075
Level of significance	NS	NS	NS

** = Significant at 1% level of probability, * = Significant at 5% level of probability, NS = Not significant

T_1 = Ambient temperature, T_2 = 4^0C temperature

P_1: Control (unwrapped)

P_2: Fruits wrapped in 50µ PP bag

P_3: Fruits wrapped in 75µ PP bag

P_4: Fruits wrapped in 100µ PP bag

Table 8. Combined effect of temperature and thickness of Polypropylene (PP) bags on vitamin C of Litchi

Treatment combination	Vitamin C content (mg/100g) at different days after storage		
	3	6	9
T_1P_1	31.14	24.14	21.34
T_1P_2	35.22	31.45	21.98
T_1P_3	35.53	31.97	22.76
T_1P_4	35.35	31.02	22.20
T_2P_1	35.18	31.26	27.47
T_2P_2	35.73	32.19	28.17
T_2P_3	36.02	32.94	29.40
T_2P_4	35.50	31.96	28.63
$LSD_{0.05}$	0.350	0.410	0.173
$LSD_{0.01}$	0.483	0.564	0.238
Level of significance	**	**	**

** = Significant at 1% level of probability, * = Significant at 5% level of probability, NS = Not significant

T_1 = Ambient temperature, T_2 = 4^0C temperature

P_1: Control (unwrapped)

P_2: Fruits wrapped in 50µ PP bag

P_3: Fruits wrapped in 75µ PP bag

P_4: Fruits wrapped in 100µ PP bag

Titratable acidity

The combined effect of thickness of PP bag and temperature had a statistically significant difference on titratable acid content of Litchi (Supplemental Table 9) at 3rd and 9th day of storage. At 6th day of storage period, the combined effect of temperature and thickness of PP bags on titratable acidity of Litchi is non-significant. The highest percentage of titratable acid content (0.50%) was observed in Litchis wrapped in PP bag of 75 µm thickness and kept in low temperature (4 ºC). The lowest percentage of titratable acid content (0.19%) was observed in control (Litchi left untreated) fruits at 9th day of storage (Table 9).

C. Postharvest disease

Different postharvest diseases had been observed at storage period. Various parameters like disease incidence, disease severity and causal pathogen were identified and investigated in the present study. The results are presented and interpreted in the following:

Disease incidence

The combined effects of thickness of PP bags and low temperature (4 ºC) were statistically significant to influence disease incidence of Litchi at different days after storage (Supplemental Table 10). The highest disease incidence (100%) was observed at control (Litchi left untreated) and Litchis wrapped in 100 µm PP bag and kept in ambient temperature and the lowest disease incidence (0.00%) was observed at all Litchis kept in 4°C temperature at 2nd, 4th, 6th, and 8th days after storage (Table 10).

Disease severity

The combined effects of thickness of PP bag and low temperature were statistically significant to influence disease severity on Litchi at different days after storage (Supplemental Table 11). The highest disease severity (51.67%) was observed at control (Litchi left untreated) followed by disease severity in 100 µm PP bags and the lowest disease severity (0.00%) was observed at 4 °C temperature of 50, 75, and 100 µm PP bags at 8th day of storage (Table 11).

Table 9. Combined effect of temperature and thickness of Polypropylene (PP) bags on titratable acidity of Litchi

Treatment combination	Titratable acidity at different days after storage		
	3	6	9
T_1P_1	0.44	0.25	0.19
T_1P_2	0.45	0.35	0.30
T_1P_3	0.45	0.33	0.25
T_1P_4	0.46	0.32	0.28
T_2P_1	0.45	0.31	0.25
T_2P_2	0.49	0.36	0.28
T_2P_3	0.50	0.37	0.29
T_2P_4	0.48	0.35	0.27
$LSD_{0.05}$	0.055	0.079	0.067
$LSD_{0.01}$	0.075	0.109	0.092
Level of significance	**	NS	**

** = Significant at 1% level of probability, * = Significant at 5% level of probability, NS= Not significant

T_1 = Ambient temperature, T_2 = 4^0C temperature

P_1: Control (unwrapped)

P_2: Fruits wrapped in 50µ PP bag

P_3: Fruits wrapped in 75µ PP bag

P_4: Fruits wrapped in 100µ PP bag

Table 10. Combined effect of temperature and thickness of Polypropylene (PP) bags on percentage of disease incidence of Litchi

Treatment combination	% Disease incidence at different days after storage			
	2	4	6	8
T_1P_1	20.00	46.67	66.67	100.00
T_1P_2	7.33	33.33	53.33	80.00
T_1P_3	0.00	26.67	46.67	66.67
T_1P_4	26.67	40.00	60.00	100.00
T_2P_1	0.00	0.00	0.00	0.00
T_2P_2	0.00	0.00	0.00	0.00
T_2P_3	0.00	0.00	0.00	0.00
T_2P_4	0.00	0.00	0.00	0.00
$LSD_{0.05}$	1.35	2.24	2.24	3.29
$LSD_{0.01}$	1.86	3.09	3.09	4.54
Level of significance	**	**	**	**

** = Significant at 1% level of probability, * = Significant at 5% level of probability, NS = Not significant
T_1 = Ambient temperature,T_2 = 4^0C temperature
P_1: Control (unwrapped)
P_2: Fruits wrapped in 50µ PP bag
P_3: Fruits wrapped in 75µ PP bag
P_4: Fruits wrapped in 100µ PP bag

Table 11. Combined effect of temperature and thickness of Polypropylene (PP) bags on percent disease severity of Litchi

Treatment combination	% Disease severity at different days after storage			
	2	4	6	8
T_1P_1	1.00	10.00	25.67	51.67
T_1P_2	0.00	5.06	12.33	19.67
T_1P_3	0.00	1.33	7.04	13.33
T_1P_4	0.00	8.67	17.67	30.67
T_2P_1	0.00	0.00	0.00	0.00
T_2P_2	0.00	0.00	0.00	0.00
T_2P_3	0.00	0.00	0.00	0.00
T_2P_4	0.00	0.00	0.00	0.00
$LSD_{0.05}$	-	0.617	0.764	0.736
$LSD_{0.01}$	-	0.850	1.053	1.015
Level of significance	-	**	**	**

** = Significant at 1% level of probability, * = Significant at 5% level of probability, NS = Not significant
T_1 = Ambient temperature,T_2 = 4^0C temperature
P_1: Control (unwrapped)
P_2: Fruits wrapped in 50µ PP bag
P_3: Fruits wrapped in 75µ PP bag
P_4: Fruits wrapped in 100µ PP bag

D. Shelf life

The combined effects of thickness of PP bags and low temperature were statistically significant to influence shelf life of Litchi at different days after storage (Supplemental Table 12). The longest shelf life (23.67 days) was observed at Litchis wrapped in 75 µm PP bag at 4 ºC temperature followed by shelf life (23.33 days) of Litchis wrapped in 50 µm and 100 µm PP bag at 4 ºC temperature and the shortest shelf life (3 days) was observed in control (Litchi left untreated) followed by shelf life (5 days) of Litchis wrapped in 100 µm PP bag at ambient temperature (Fig. 3).

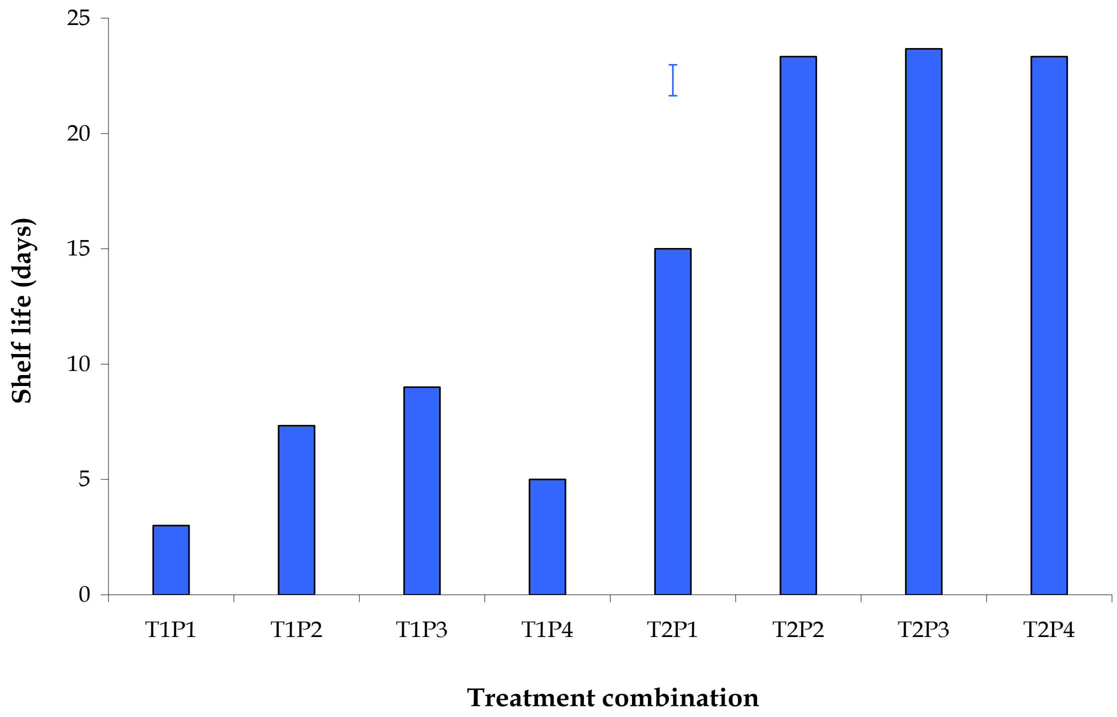

Fig. 3. Combined effect of temperature and thickness of Polypropylene (PP) bags on shelf life (days) of Litchi
Where, T_1 = Ambient temperature, T_2 = 4^0C temperature
P_1: Control (unwrapped), P_2: Fruits wrapped in 50µ PP bag, P_3: Fruits wrapped in 75µ PP bag, P_4: Fruits wrapped in 100µ PP bag

Discussion

The experiment was carried out at the Laboratory of the Department of Horticulture, Biochemistry & Molecular Biology and Plant Pathology of Bangladesh Agricultural University, Mymensingh during the period from May to September, 2016. The data were recorded at 1, 2, and 3 days interval after storage (DAS) on different characteristics of physical, chemical and microbial properties and also shelf life of Litchi.

Browning of pericarp is one of the most significant features in respect to quality of Litchi in storage period. The outer peel of lychee fruits before storage was red. After 3-6 days of storage the outer and inner peel retained their colors. After 6-9 days of storage, both the inner and outer peel had more color intensity. The pulp was greyish-white before storage and retained this color throughout the experiment. Kesta and Leelawatana, (1990) investigated and proved that packing within plastic bags and sealed containers can reduce the rate of pericarp color change.

Pulp to peel ratio is also an important feature in respect of quality of Litchi during storage. The pulp to peel ratio showed an increasing rate up to the 6^{th} day of storage and decreased thereafter. The highest pulp to peel ratio during the entire storage period was observed at control (Litchi left untreated) fruits at 6^{th} day of storage. The lower pulp to peel ratio was observed in Litchis kept in low temperature (4 ºC) at the time of storage. The value of pulp to peel ratio of 3^{rd} day is higher than 9^{th} day and it is observed in all Litchis kept in ambient temperature and also in Litchis kept in 4 ºC without wrapping.

The lessening in weight is predictable to the physiological loss in weight due to respiration and transpiration of water through peel tissue, and other organic changes taking place in the Litchi. The maximum weight loss occurred in Litchis kept in ambient temperature whereas the minimum weight loss occurred in Litchis kept in low temperature (4 ºC). Weight loss of lychee fruit during storage increased with storage time. Glahan (2001) stated that respiration occurs continuously after harvest fresh and reaches a peak depending on the species and variety. Respiration results in the release of water from Litchi fruit causing weight loss. In the present experiment, weight loss had no impact on shriveling of the Litchi fruit which is similar to that reported for other fruits (Glahan, 2004a,b). According to Pesis et al. (2002), the accumulation of ethanol and acetaldehyde of Litchi fruit under modified atmosphere packaging can influence the storage life, due to the anaerobic respiration. Due to respiration after harvest, weight loss occurs rapidly. This result is agreement with van Meeteren and Aliniaeifard (2016) and Aliniaeifard and van Meeteren (2016).

Generally the moisture content decreased with the increase in storage time under different postharvest treatments. At the 9th day of storage period, the moisture contents were 80.76%, 80.18%, 80.10%, 79.80%, 79.00%, 78.75%, 78.28%, and 76.43% by T_2P_3, T_2P_2, T_2P_4, T_1P_3, T_2P_1, T_1P_2, T_1P_4, and T_1P_1 respectively. These decreasing trends were also supported by Gaur and Singh (1987) and by Joshi and Roy (1988). A rapid moisture loss of Litchi fruit occurs during harvesting and transportation if improper packaging is employed. Immediate and fast pre-cooling are important in the cold chain for Litchi fruit and can remove field heat and provide effective temperature management during subsequent storage or shipment. The results of this experiment were supported by the findings of Tongdee et al. (1999) and Bagshaw et al. (1994). In contrast, the percentage of dry matter content increased with the increase in storage duration.

The increasing trend of percentage of total soluble solids contents of fruit during storage could be attributed mainly to the breakdown of starch into simple sugars during ripening along with a proportional increase in TSS and further hydrolysis decreased the TSS during storage. Similar result found by Bolaños et al. (2010).

Generally the titratable acidity content decreased with the increase in storage time under different postharvest treatments. At the 9th day of storage period, the titratable acidity was 0.30, 0.29, 0.28, 0.28, 0.27, 0.25, 0.25, and 0.19 by T_1P_2, T_2P_3, T_2P_2, T_1P_4, T_2P_4, T_1P_3, T_2P_1, and T_1P_1 respectively. In the present investigation, decrease in the percentage of titratable acidity observed during storage agrees with the results of Mohajan (1997) and Mitra et al. (1996). The decrease in titratable acidity during storage may be attributed to the utilization of organic acids in respiratory process and other biodegradable reactions (Ulrich, 1974). Total soluble solids and titratable acidity content of Litchi fruit changed throughout the storage period. This may be a result of storage conditions which may reduce metabolic processes in the Litchi fruit. Decreases in TSS and TA of Litchi are mainly due to respiration that consumes the nutrient substances of fresh Litchi (Feng et al., 2011). This result is in agreement with Xu, et al. (2019) and Bolaños et al. (2010).

The storage methods used in this study could be implemented in the postharvest handling of Litchi and extends the shelf-life of products as found in Gros Michale (Glahan and Kerdsiri, 2001) banana ‘Kluai Khai’ (Glahan and Chockpachuen, 2003) and longkong (Glahan and Adireklap, 2005).

Vitamin C content is one of the most important factors in Litchi at storage period. Day by day the content of Litchi vitamin C was decreased. The highest vitamin C content (36.02, 32.94, and 29.40 mg/100 g) was observed at Litchis kept in 4°C temperature and wrapped in 75 µm PP bag and the lowest rate of vitamin C content (31.14, 24.14, 21.34 mg/100g) was observed in control (Litchi left untreated) at 3rd, 6th, and 6th days after storage. This result is agreement with Cao et al. (2019); Lafarga et al. (2018) and Duan et al. (2015). Among the treatments, the fruits kept in 75 µm PP bag at 4 °C temperature were found the most effective in declining the decrease in vitamin C content of fruit pulp. Mohajan (1997) stated that vitamin C content decreased during storage period and the present finding was also in complete agreement with that result.

pH is also an important feature in respect of quality of Litchi during storage. The combined effect of thickness of PP bags and low temperature (4 ºC) on pH of Litchi was non-significant. The pH showed an increasing rate up to the entire storage period. The highest pH during the entire storage period (4.14) was observed at Litchis wrapped in 100 µm PP bag and kept in ambient temperature at 9th day of storage. The lowest pH (4.01) was observed in Litchis kept in low temperature (4 ºC) at 9th day of storage. Further, it was noticed that the pH of fruit pulp was gradually increased during the total storage period. Similar result was found by Md. Aklimuzzaman et al. (2011). The increase in pulp pH may be due to continuous falling of acidity during storage. Increased of pulp pH observed in the present study was in agreement with the findings of Tongdee et al. (1982), who found that pulp pH of Litchi, increased with storage duration.

According to Zhuang et al. (1998) and Coates et al. (1994), Litchi fruits are very susceptible to postharvest decay. The highest disease incidence (100%) was observed at control (Litchi left untreated) fruits and also in fruits wrapped in PP bag of 100 µm thickness and kept in ambient temperature and the lowest disease incidence (0.00%) was observed at all treatments kept in low temperature (4 ºC) at unwrapped, 50, 75, and 100 µm PP bags at 8th day of storage. Low temperature played the vital role in controlling the disease incidence.

Disease severity level trended to increase with duration of storage. The highest disease severity (51.67%) was observed at control (Litchi left untreated) fruits followed by Litchi fruits (30.67%) wrapped in PP bag of 100 µm thickness and kept in ambient temperature and the lowest disease severity (0.00%) was observed at all treatments kept in low temperature (4 ºC) at unwrapped, 50, 75, and 100 µm PP bags at 8th day of storage. Mainly low temperature prevented the disease severity.

The extension of shelf life of fruits has been one of the most important concerns of the researchers. Moisture loss, pericarp browning and microbial decay decreases the shelf life of Litchi. In the combined effects of thickness of PP bag and low temperature the longest shelf life (23.67 days) was observed at Litchis wrapped in PP bag of 75 µm thickness and kept in low temperature (4 ºC) followed by Litchis (23.33 days) wrapped in PP bag of 50 µm and 100 µm thickness and kept in low temperature (4 ºC) and the shortest shelf life (3.00 days) was observed in control (Litchi left untreated) fruits. Jiang and Fu (1999) suggested that a relative humidity (RH) of 85–95% appear to be optimal for storage. However, higher RH was conducive to water soaking and decays. According to Huang and Wang (1990), Litchi fruits are more tolerant to low temperature and, thus, can be stored in the low temperature range of 1–5°C, but the decline in visual appearance and disease development eventually limit longevity. Modified control packaging is an alternative to extension storage life of Litchi.

Conclusion

It was found that the postharvest treatments caused significant effects on pericarp browning, pulp to peel ratio, moisture and dry matter content, total weight loss, TSS content, vitamin C content, titratable acidity, disease incidence, disease severity and shelf life of Litchi. Litchi held at 75 μm thickness of PP bag and stored at 4°C yielded the best result especially in relation to the reduction of pericarp browning, weight loss, disease incidence and severity compared to other treatments, which ultimately resulted in prolonged shelf life of Litchi.

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Conflict of Interest

The authors have no conflict of interest to report.

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