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Research Article

Color Retention and Extension of Shelf Life of Litchi Fruit in Response to Storage and Packaging Technique

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Abstract

Background and Objective: Litchi is a tropical fruit of high commercial value and high demand in national and international markets. Its main postharvest problem is the rapid pericarp browning, color loss and rotting which is due to environmental factors such as temperature and storage technique. Color is the most important external characteristic to assess ripeness and postharvest life and is a major factor in the consumer's purchase decision. The objective of the study was to investigate the effect of different storage temperature and simple packaging technique on color retention, reducing pericarp browning and extension of marketable life of litchi fruit. **Methodology:** The experiment was carried out in the laboratory of postharvest technology Division of Bangladesh Agricultural Research Institute (BARI) using CRD factorial arrangement with 3 times of replication. A two way analysis of variances (ANOVA) was conducted by using statistical method (MSTAT-C). **Results:** The result showed that storage of litchi fruit at $5\pm1°C$ significantly ($p<0.05$) increased the hue angle, light and chroma than the fruits stored at ambient condition. The fruit stored at $5\pm1°C$ inhibited physiological loss in weight and decay loss compared to others. The nutritional study of the fruit stored at $5\pm1°C$ had significantly ($p<0.05$) higher than stored at ambient condition. Total soluble solid content increased with development of color and increasing storage periods. In case of packaging technique, fruit packed in non-perforated polyethylene bag wrapping with browning paper increased the firmness, reduced browning and retention of higher color value than other packaging techniques under the temperature of $5\pm1°C$. The marketable life of the fruits significantly ($p<0.05$) increased (30 days more) using non-perforated polyethylene bag wrapping with browning paper (0.06 mm) under the temperature of $5\pm1°C$ compared to others. **Conclusion:** The result served as a bench mark to sub-tropical and litchi growing and possible exportable areas like Bangladesh in which atmospheric temperature mostly approaches to 30°C and somewhere above 30°C.

Key words: Litchi color, storage temperature, nutritional parameter, marketable life, pericarp

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

The litchi fruit has a high demand in exotic market because of its appealing natural color, rich taste and aroma. Its red pericarp color is an important attribute of the fruit as it turns into brown color within a day or two after harvesting. Pericarp browning has long been considered as the main postharvest problem of litchi[1]. Under ambient condition, once harvested, litchi fruits have a very short postharvest life. Within 1-2 days after harvesting of the fruits, the red color of the pericarp turn to brown, this drastically reduces the commercial value of the fruits[2]. The fruit is highly perishable in nature due to microbial and physiological spoilage and lasts for only 2-3 days at ambient temperature (26±2°C). Therefore, the postharvest losses of litchi are estimated to be 20-30% of the harvested fruits and can even be as high as 50% prior to consumption[1]. In Bangladesh, the loss is also high where it is estimated as 37.10% although its production is mainly concentrated in the Northern and Eastern region[3].

The fruit is highly prized, especially in Asia and is a valuable international commodity. Perishable nature of the fruit limits marketing in countries without good postharvest handling facilities. Therefore, it must be marketed and consumed quickly. The fruit is particularly prone to water loss. In the first instance, dehydration only caused cosmetic injury with most of the initial water loss from the pericarp, due to which it loss color and turn dull brown. Color is one of the most important and complex attributes of litchi fruit quality and hence considerable attention has been given to retain its color and reducing pericarp browning.

Water loss and browning can be overcome with packages that maintain high humidity around the fruit. However, these increase the risk of rots[4]. A number of chemical measures can help to control these rots. In recent years, there has been increasing concern about chemical residues in fruit, particularly when some consumers are sensitive to chemicals. Good package designs not only contribute a great deal to the quality image of the product but also can maintain freshness, prevent browning, rotting and fruit decay during transit for marketing to distance places. On the other hand, litchis available in the fresh market are sold in bunches of 50 and 100 without any packaging. Many litchis of bunches fall, thereby customers seldom get the actual number. A good packaging system can overcome this problem as well as increases marketable life. However, still there is no information in Bangladesh context regarding which temperature and packaging technique is optimum for reducing water loss, pericarp browning and retaining fresh color with extending marketable life of the litchi fruit. Therefore, an assumption has been made, non-perforated polyethylene bag may reduce the water loss and using browning paper inside the non-perforated polyethylene bag may be effective to absorb the excess amount of moisture that can contribute to reduce browning and rotting along with fresh color of the fruit. The objective of the study was to investigate the effect of different storage temperature and simple packaging technique on color retention, reducing pericarp browning and extension of marketable life of litchi fruit.

MATERIALS AND METHODS

Study area: The study was conducted in Postharvest Technology Division, Bangladesh Agricultural Research Institute (BARI), Gazipur-1701, Bangladesh from June, 2017-July, 2017.

Experimental materials and treatments: Litchi fruits of Bombay cultivar were harvested from the farmer's field of Marta, Gazipur Sadar. In farmer's field, each bunch contained fifty fruits. After shipment in laboratory, then the fruits were sorted and then forty fruits were assigned/treatment for both non-destructive and destructive measurements. The experiment was designed CRD factorial with 3 replications where the treatment combination was according to the Table1. Data were recorded at 6 days interval.

Data collected

Measurement of the color of the fruits: Litchi external color was evaluated with a Chroma Meter (Model CR-400, Minolta Corp., Japan). CIE L*a*b* coordinates were recorded using D65 illuminates and a 10° standard observer as a reference system. L* Iis the lightness, a* (-greenness to +redness) and b* (-blueness to + yellowness) are the chromacity coordinates. The a* and b* values were converted to chroma [$C = (a^{*2}+b^{*2})^{1/2}$] and hue angle [$h = \tan^{-1}(b^*/a^*)$]. Before measurement, the equipment was calibrated against a standard white tile. Three readings were taken using five fruits from each treatment on the day of storage and during termination of the marketable life.

Weight loss (%): It was determined by periodical weighing of litchi fruit using digital electronic balance and expressed as percentage of original weight. Damaged litchis were also included with it. The weight loss was calculated as following formula of Kurubar[5].

$$WL\ (\%) = \frac{IW - FW}{IW} \times 100$$

Table 1: Combined treatment of litchi fruit

Treatment combinations	Details
A0B0C0	Without wash and without packaging and stored at ambient condition
A0B0C1	Without wash and without packaging and stored at 5±1°C (cool room)
A1B0C0	Wash with clean water and without packaging and stored at ambient condition
A1B0C1	Wash with clean water and without packaging and stored at 5±1°C
A2B0C0	Wash with NaOCl and without packaging and stored at ambient condition
A2B0C1	Wash with NaOCl and without packaging and stored at 5±1°C
A3B0C0	Dipping in chitosan and without packaging and stored at ambient condition
A3B0C1	Wash with chitosan and without packaging and stored at5±1°C
A0B1C0	Without wash and packed in 1% perforated polyethylene bag wrapping with browning paper and stored at ambient condition
A0B1C1	Without wash and packed in 1% perforated polyethylene bag wrapping with browning paper and stored at 5±1°C
A1B1C0	Wash with clean water and packed in 1% perforated polyethylene bag wrapping with browning paper and stored at ambient condition
A1B1C1	Wash with clean water and packed in 1% perforated polyethylene bag wrapping with browning paper and stored at 5±1°C
A2B1C0	Wash with NaOCl and packed in 1% perforated polyethylene bag wrapping with browning paper and stored at ambient condition
A2B1C1	Wash with NaOCl and packed in 1% perforated polyethylene bag stored at 5±1°C
A3B1C0	Dipping in chitosan and packed in 1% perforated polyethylene bag wrapping with browning paper and stored at ambient condition
A3B1C1	Dipping in chitosan and packed in 1% perforated polyethylene bag wrapping with browning paper and stored at 5±1°C
A0B2C0	Without wash and packed in 1.5% perforated polyethylene bag wrapping with browning paper and stored at ambient condition
A0B2C1	Without wash and packed in 1.5% perforated polyethylene bag wrapping with browning paper and stored at 5±1°C
A1B2C0	Wash with clean water and packed in 1.5% perforated polyethylene bag wrapping with browning paper and stored at ambient condition
A1B2C1	Wash with clean water and packed in 1.5% perforated polyethylene bag wrapping with browning paper and stored at 5±1°C
A2B2C0	Wash with NaOCl and packed in 1.5% perforated polyethylene bag wrapping with browning paper and stored at ambient condition
A2B2C1	Wash with NaOCl and packed in 1.5% perforated polyethylene bag wrapping with browning paper and stored at 5±1°C
A3B2C0	Dipping in chitosan and packed in 1.5% perforated polyethylene bag wrapping with browning paper and stored at ambient condition
A3B2C1	Dipping in chitosan and packed in 1.5% perforated polyethylene bag wrapping with browning paper and stored at 5±1°C
A0B3C0	Without wash and packed in non-perforated polyethylene bag wrapping with browning paper and stored at ambient condition
A0B3C1	Without wash and packed in non-perforated polyethylene bag wrapping with browning paper and stored at 5±1°C
A1B3C0	Wash with clean water and packed in non-perforated polyethylene bag wrapping with browning paper and stored at ambient condition
A1B3C1	Wash with clean water and packed in non-perforated polyethylene bag wrapping with browning paper and stored at 5±1°C
A2B3C0	Wash with NaOCl and packed in non-perforated polyethylene bag wrapping with browning paper and stored at ambient condition
A2B3C1	Wash with NaOCl and packed in non-perforated polyethylene bag wrapping with browning paper and stored at 5±1°C
A3B3C0	Dipping in chitosan and packed in non-perforated polyethylene bag wrapping with browning paper and stored at ambient condition
A3B3C1	Dipping in chitosan and packed in non-perforated polyethylene bag wrapping with browning paper and stored at 5±1°C

Where:

WL = Weight loss of litchi
IW = Initial weight of litchi
FW = Final weight of litchi

Decay loss (%): The litchi fruits were observed visually for rotting and microbial infection. Percent decay incidence was identified and calculated using the formula of Molla *et al*.[6]:

$$D_L\ (\%) = \frac{D_0}{D} \times 100$$

Where:

D_L = Decay loss
D_o = Number of decayed litchis
D = Total number of litchi

Fruit firmness (N): Fruit firmness was determined to measure fruit puncture resistance by using a digital Firmness Tester (DFT 14, AgroTechnologie, France) whereby each of 8 fruit as a replicate was placed on a sample platform at a constant probe speed of 2 mm sec^{-1} on two sides of the same fruit. Firmness was measured based on millimeters of fruit deformation using 8 mm diameter flathead probe which penetrates the fruit peel by 5 mm. The mean value of each fruit puncture resistance was calculated and expressed in nm.

Marketable life (day): Marketable life of the fruit was recorded on daily basis until the fruits spoilage level, damaging, shriveling etc. reaches up to 10%, which is considered as maximum marketable life limit.

Nutritional analysis: β-carotene was done by the extracting of 3 g product sample with acetone (Fisher Scientific Ltd., UK) and petroleum ether. It was further purified with acetone, metabolic KOH and distilled water. The resulting solution was filtered with anhydrous sodium sulphate and read on a spectrophotometer (T-80, PG Instrument Ltd., UK) at 451 nm against petroleum ether as a blank. Petroleum ether and its optical density measured at 451 nm Fikselova et *al*.[7]. pH was measured using a glass electrode pH meter (Delta 320, Mettler, Shanghai). Titrable Acidity (%) by treating against standard NaOH solution, vitamin-C content (mg/100 g) by 2, 6- Diclorophenol-Indophenol Visual Titration Method and TSS (°Brix) by hand digital refractometer, reducing and total sugar content was determined according to Ghadge and Jadhav[8].

Statistical analysis: A two way analysis of variances (ANOVA) was conducted by using statistical method (MSTAT-C). The difference was quantified by Least Significant Difference (LSD ($p<0.01$, $p<0.05$)).

RESULTS AND DISCUSSION

Physiological loss in weight (PLW) of litchi fruits during storage: PLW of litchi fruits increased gradually with the advancement of storage periods (Fig. 1). A statistically significant difference was observed in PLW among the different treatments. Litchi fruit stored at 5±1°C (A0B3C1) had the lowest ($p<0.01$) PLW during the storage time. The highest PLW was recorded in all litchi fruits stored at ambient condition followed by stored at 5±1°C (A0B3C1). The higher PLW may be due to more water loss and lower levels of relative humidity in ambient condition. Water is the main component of fruits and vegetables, therefore, reduction of its loss from the commodity is the most critical requirement for maintenance of postharvest quality attributes[9]. Pericarp browning of litchi fruit directly correlates with moisture loss[2]. The fruit stored at ambient condition contained lower levels of relative humidity than the fruit stored at 5±1°C, hence the rate of PLW was more obvious and litchi fruit rapidly loses its attractive bright red color. These results are partially agreement with the findings of Salami *et al.*[9]. The lower PLW of litchi fruit stored at 5±1°C with non-perforated polyethylene bag wrapping with browning paper could be attributed to higher relative humidity (95±1%). The non-perforated polyethylene bag wrapping with browning paper enhanced the accumulation of higher relative humidity and maintained a high humidity environment for fruit inside the non-perforated polyethylene bag. Thus the non-perforated polyethylene bag contributed to cause lower moisture loss. The lower moisture loss influenced the lower PLW of litchi fruit stored in non-perforated polyethylene bag under 5±1°C. Hence, storage of litchi fruit at ambient condition is not advisable, as it may result in excessive PLW.

Firmness of litchi fruits during storage: Firmness of all litchi fruit stored at ambient condition progressively decreased during advancement of storage time followed by litchi fruit stored at 5±1°C with 95±1% relative humidity (Fig. 2). There was a significant difference ($p<0.01$) among the different treatments. Litchi fruit stored at 5±1°C gained significantly ($p<0.01$) the highest value of firmness than the fruits stored at ambient condition (Fig. 2). At 6 days of storage, litchi fruit firmness was higher at ambient condition but after 12 days of storage, the fruit firmness continuously decreased over the 30 days of storage periods. But the fruit stored in non-perforated polyethylene bag wrapping with browning paper under 5±1°C with 95±1% relative humidity increased the firmness from 6-30 days of storage periods (Fig. 2). The increasing firmness of the litchi fruit may be due to modified packaging technique by browning paper in non-perforated polyethylene bag. However, a good association was found between the fruit stored at low temperature and firmness. Low temperature may be contributed to reduce the water loss of the fruit. Thus less water loss resulted to increase the firmness of the fruit stored at 5±1°C with 95±1% relative humidity.

Hue angle, chroma and light of litchi fruit during storage: At initial day of storage, no major changes of hue angle, chroma and light were observed (Fig. 3). Among the different treatments, litchi fruit stored at ambient condition terminated their shelf life after 3, 6 and 12 days of storage. Hence, litchi fruit stored in non-perforated polyethylene bag wrapping with

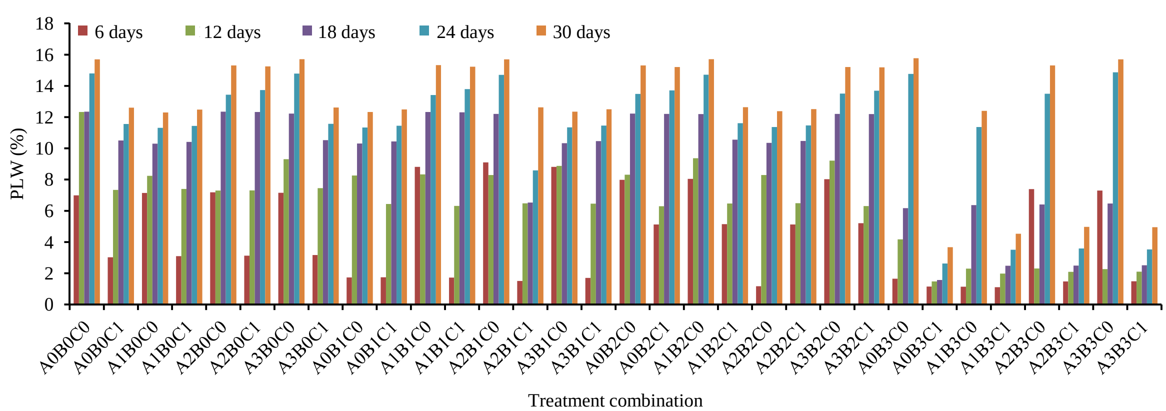

Fig. 1: PLW of litchi fruits during 30 days of storage under different conditions

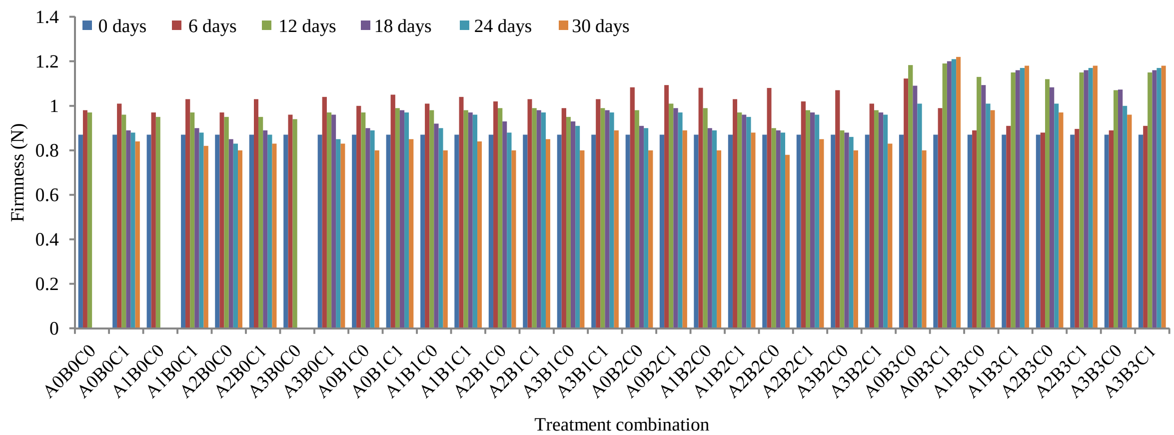

Fig. 2: Firmness of litchi fruit stored under different storage conditions

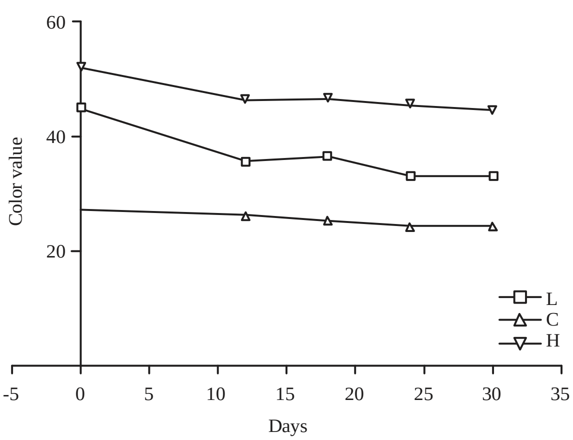

Fig. 3: Hue angle, chroma and light during 30 days of storage

browning paper under 5±1°C with 95±1% relative humidity were investigated for color at the end of the storage periods. Results showed that hue angle was slightly changed up to 12 days of storage. Then the hue angle was almost similar up to 30 days of storage (Fig. 3). The value of L of litchi fruit gradually decreased up to 12 days of storage and then it was remain constant up to 30 days of storage. Litchi fruit stored in non-perforated polyethylene bag wrapping with browning paper under 5±1°C with 95±1% relative humidity retained the characteristics color of the fruits than the fruits stored at ambient condition. No major changes of chroma were observed up to the 30 days of storage. This would mean that the final chroma contained in fruits stored in non-perforated polyethylene bag wrapping with browning paper at 5±1°C retained the original color of litchi fruits. These results are in agreement with Semeerbabu *et al.*[10], who suggested that the litchi fruit can have a storage life of around 30 days at 3-5°C. Postharvest pericarp browning and fruit quality deterioration can be effectively delayed by cold storage[11]. Color is one of the important quality attributes for consumer acceptability of foods, particularly for fresh fruits and vegetables[12].

Decay loss of litchi fruits during storage: After 12 days of storage, PLW was almost stable where the decay loss continuously increased with the increase in storage periods, irrespective to the treatments. Decay loss was initiated after 3 and 6 days of storage at ambient condition than the fruit stored at 5±1°C (Fig. 4). It indicates that the trend of decay loss was dramatically increased with the advancement of storage periods under ambient condition. No decay loss was found up to 18 days of storage for the litchi fruit stored at 5±1°C in non-perforated polyethylene bag. After 30 days of storage, only 2.0% decay loss was observed for without wash and packed in non-perforated polyethylene bag wrapping with browning paper under the temperature of 5±1°C. During storage, the incidence of the decay was identified as spot rotting which was the main cause to terminate the marketable life of litchi fruit. However, the litchi fruit stored at 5±1°C exhibited significantly less decay loss throughout the storage periods (Fig. 4). The reduced decay loss could be due to suppressed micro-cracks of litchi pericarp[2] because micro-cracks act as major entry points of pathogens.

Titrable acidity, total soluble solid, pH, vitamin-C, reducing and total sugar of litchi fruits during storage: Titrable acidity (TA) of litchi fruit was recorded at initial day of storage and before terminated their marketable life (12 and 30 days). TA of litchi fruit stored at different conditions was statistically significant over the storage periods. But at 12 days of storage, a non-significant difference was detected among the treatments (Table 2). TA was significantly higher ($p<0.05$) in fruit stored at 5±1°C and wrapping with browning paper in non-perforated polyethylene bag than the fruit stored at ambient condition (Table 2) during 30 days of storage periods. At ambient temperature as well as high temperature, the respiration rate as well as ripening rate was higher than at low temperature and that might be reason why the highest TA percentage was recorded in fruits stored at 5±1°C

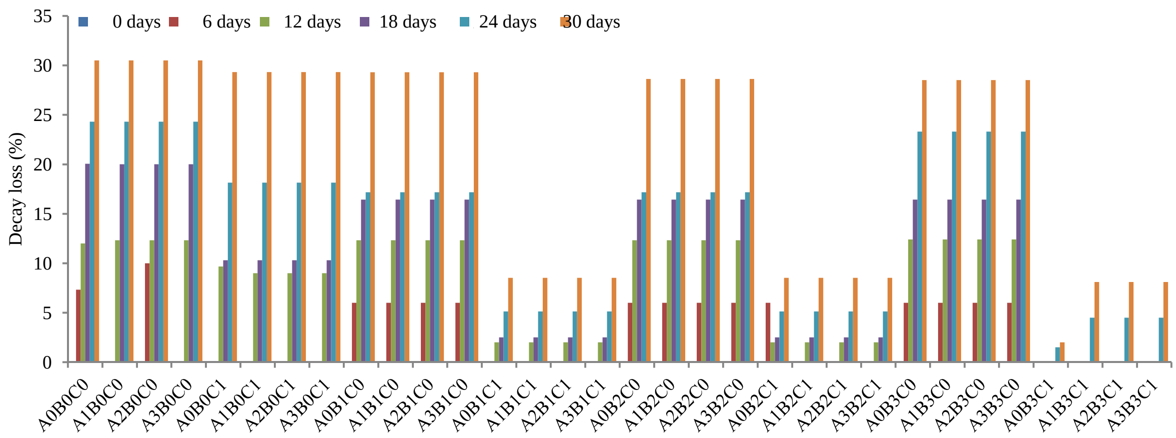

Fig. 4: Decay of litchi fruit stored under different storage conditions

Table 2: Acidity, pH, reducing and total sugar of litchi fruits after storage of 12 and 30 days

	Titrable acidity (days)			pH (days)			Reducing sugar (days)			Total sugar (days)		
Treatment	0	12	30	0	12	30	0	12	30	0	12	30
A0B0C0	0.19	0.29	0.00^{d}	4.23	4.20^{f}	0.00^{b}	9.38	9.13^{f}	0.00^{h}	11.40	9.69^{efg}	0.00^{c}
A0B0C1	0.19	0.29	0.00^{d}	4.23	4.24^{cdef}	0.00^{b}	9.38	9.14^{f}	0.00^{h}	11.40	9.99^{d}	0.00^{c}
A1B0C0	0.19	0.29	0.00^{d}	4.23	4.25^{bcdef}	0.00^{b}	9.38	9.14^{f}	0.00^{h}	11.40	9.70^{ef}	0.00^{c}
A1B0C1	0.19	0.29	0.00^{d}	4.23	4.22^{ef}	0.00^{b}	9.38	9.18^{f}	0.00^{h}	11.40	9.98^{d}	0.00^{c}
A2B0C0	0.19	0.29	0.00^{d}	4.23	4.22^{ef}	0.00^{b}	9.38	9.16^{f}	0.00^{h}	11.40	9.60^{h}	0.00^{c}
A2B0C1	0.19	0.29	0.00^{d}	4.23	4.30^{ab}	0.00^{b}	9.38	9.15^{f}	0.00^{h}	11.40	9.99^{d}	0.00^{c}
A3B0C0	0.19	0.29	0.00^{d}	4.23	4.23^{ef}	0.00^{b}	9.38	9.14^{f}	0.00^{h}	11.40	9.65^{fgh}	0.00^{c}
A3B0C1	0.19	0.29	0.00^{d}	4.23	4.24^{def}	0.00^{b}	9.38	9.30^{e}	0.00^{h}	11.40	9.98^{d}	0.00^{c}
A0B1C0	0.19	0.29	0.00^{d}	4.23	4.22^{ef}	0.00^{b}	9.38	9.16^{f}	0.00^{h}	11.40	9.64^{gh}	0.00^{c}
A0B1C1	0.19	0.29	0.48^{bc}	4.23	4.30^{a}	4.47^{a}	9.38	9.58^{bcd}	8.58^{bcd}	11.40	11.38^{c}	10.46^{a}
A1B1C0	0.19	0.30	0.00^{d}	4.23	4.23^{ef}	0.00^{b}	9.38	9.15^{f}	0.00^{h}	11.40	9.65^{fgh}	0.00^{c}
A1B1C1	0.19	0.29	0.52^{abc}	4.23	4.28^{abcd}	4.47^{a}	9.38	9.58^{cd}	8.59^{abc}	11.40	11.67^{b}	10.46^{a}
A2B1C0	0.19	0.28	0.00^{d}	4.23	4.23^{ef}	0.00^{b}	9.38	9.31^{e}	0.00^{h}	11.40	9.67^{efg}	0.00^{c}
A2B1C1	0.19	0.30	0.47c	4.23	4.29^{abcd}	4.47^{a}	9.38	9.60^{bcd}	8.50^{fg}	11.40	11.69^{ab}	10.43^{a}
A3B1C0	0.19	0.29	0.00^{d}	4.23	4.22^{ef}	0.00^{b}	9.38	9.30^{e}	0.00^{h}	11.40	9.70^{e}	0.00^{c}
A3B1C1	0.19	0.30	0.48^{bc}	4.23	4.27^{abcde}	4.47^{a}	9.38	9.57^{cd}	8.51^{f}	11.40	11.68^{ab}	10.45^{a}
A0B2C0	0.19	0.29	0.00^{d}	4.23	4.20^{f}	0.00^{b}	9.38	9.31^{e}	0.00^{h}	11.40	9.70^{ef}	0.00^{c}
A0B2C1	0.19	0.30	0.47c	4.23	4.30^{ab}	4.47^{a}	9.38	9.55^{d}	8.52^{ef}	11.40	11.68^{ab}	10.44^{a}
A1B2C0	0.19	0.29	0.00^{d}	4.23	4.20^{f}	0.00^{b}	9.38	9.31^{e}	0.00^{h}	11.40	9.69^{efg}	0.00^{c}
A1B2C1	0.19	0.30	0.47^{c}	4.23	4.31^{a}	4.48^{a}	9.38	9.60^{bc}	8.54^{def}	11.40	11.68^{ab}	10.43^{a}
A2B2C0	0.19	0.29	0.00^{d}	4.23	4.20^{f}	0.00^{b}	9.38	9.31^{e}	0.00^{h}	11.40	9.70^{e}	0.00^{c}
A2B2C1	0.19	0.30	0.47^{bc}	4.23	4.29^{abcd}	4.48^{a}	9.38	9.58^{cd}	8.57^{bcde}	11.40	11.68^{ab}	10.45^{a}
A3B2C0	0.19	0.30	0.00^{d}	4.23	4.22^{ef}	0.00^{b}	9.38	9.32^{e}	0.00^{h}	11.40	9.65^{fgh}	0.00^{c}
A3B2C1	0.19	0.30	0.48^{bc}	4.23	4.29^{abcd}	4.48^{a}	9.38	9.63^{ab}	8.59^{bcd}	11.40	11.66^{b}	10.44^{a}
A0B3C0	0.19	0.30	0.00^{d}	4.23	4.20^{f}	0.00^{b}	9.38	9.31^{e}	0.00^{h}	11.40	9.69^{efg}	0.00^{c}
A0B3C1	0.19	0.29	0.53a	4.23	4.30^{a}	4.48^{a}	9.38	9.67^{a}	8.64^{a}	11.40	11.66^{b}	10.45^{a}
A1B3C0	0.19	0.30	0.00^{d}	4.23	4.21^{f}	0.00^{b}	9.38	9.31^{e}	0.00^{h}	11.40	9.681^{efg}	0.00^{c}
A1B3C1	0.19	0.31	0.52^{ab}	4.23	4.31a	4.47^{a}	9.38	9.66^{a}	8.61^{ab}	11.40	11.69^{ab}	10.43^{a}
A2B3C0	0.19	0.30	0.00^{d}	4.23	4.25^{bcdef}	0.00^{b}	9.38	9.31^{e}	0.00^{h}	11.40	9.688^{efg}	0.00^{c}
A2B3C1	0.19	0.31	0.52^{ab}	4.23	4.28^{abcd}	4.48^{a}	9.38	9.65^{a}	8.55^{cdef}	11.40	11.66^{b}	10.34^{b}
A3B3C0	0.19	0.30	0.00^{d}	4.23	4.20^{f}	0.00^{b}	9.38	9.31^{e}	0.00^{h}	11.40	9.67^{efg}	0.00^{c}
A3B3C1	0.19	0.31	0.52^{abc}	4.23	4.29^{abc}	4.45^{a}	9.38	9.58^{cd}	8.46^{g}	11.40	11.73^{a}	10.34^{b}
LSD	-	NS	**	-	**	**	-	**	**	-	**	**
CV (%)	-	4.35	8.45	-	0.68	0.87	-	0.21	0.57	-	0.35	0.40

Small letter in the same column differ significantly **Indicates significant level at 1% and * indicates significant level at 5%

temperature than those stored at ambient temperature. These results were in agreement with the findings of Arah *et al.*[13]. pH of the litchi fruit stored at 5±1°C under different packaging technique was higher and statistically significant than the fruit stored at ambient condition during 12 and 30 days of storage periods (Table 2). Reducing and total sugar was significantly higher in fruit stored at 5±1°C under different packaging technique than the fruit stored at ambient condition (Table 2). Moreover, reducing and total sugars were positively correlated to TA and pH under the fruit stored at 5±1°C than ambient temperature (Table 2). The positive correlation between sugars and pH, on the other hand between sugars and TA, means that plants with high sugars generally have more free organic acids and less hydrogen ion concentration than plants with low sugars. Similar findings were also made by Azene et *al.*[14] and Tadesse *et al.*[15]. These studies also show that the TA, pH and sugars content was increased during advancement of storage periods (Table 2). May be that is why, the lower incidence of fungal infection and decay loss was recorded for the litchi fruit stored at 5±1°C than ambient temperature. These results were strongly supported by Rab *et al.*[16] where they had shown that low temperature may not be able to develop pathogens.

Vitamin-C content of litchi fruit stored at 5±1°C was highly significant than ambient condition (Table 2). The fruit stored at 5±1°C and wrapping with browning paper in non-perforated polyethylene bag had significantly higher vitamin-C content for 30 days of storage periods although it was decreased with increasing storage periods. Vitamin-C content was known to decline under prolonged-storage conditions[17] probably owing to the utilization of different organic acids during fruit respiration or their likely conversion to the sugars. Oxidative deterioration of vitamin-C contents may also leads to its rapid reduction[18]. However, significantly higher vitamin-C contents in 5±1°C and wrapping with browning paper in non-perforated polyethylene bag could be due to inhibited senescence and reduced oxidation of various organic acids[18]. β-carotene was significantly differ among the different treatments. Litchi fruit stored at 5±1°C under different packaging technique had higher β-carotene content than ambient and open condition. But the β-carotene content was decreased with the increasing storage periods (Table 3). However, the results indicate that temperature had a large effect on development of carotenoids. There was

Table 3: Vitamin-C, β-carotene and total soluble solid of litchi fruits after storage of 12 and 30 days

Treatment combination	Vitamin-C (days)			β-carotene (days)			TSS (days)		
	0	12	30	0	12	30	0	12	30
A0B0C0	26.77	23.68^{d}	0.00^{g}	17.23	8.323^{de}	0.00^{c}	17.33	17.43^{b}	0.00
A0B0C1	26.77	24.50^{c}	0.00^{g}	17.23	9.033^{c}	0.00^{c}	17.33	17.44^{b}	0.00^{c}
A1B0C0	26.77	23.68^{d}	0.00^{g}	17.23	8.323^{de}	0.00^{c}	17.33	17.43^{b}	0.00^{c}
A1B0C1	26.77	24.50^{c}	0.00^{g}	17.23	9.027^{c}	0.00^{c}	17.33	17.42^{b}	0.00^{c}
A2B0C0	26.77	3.68^{d}	0.00^{g}	17.23	8.320^{de}	0.00^{c}	17.33	17.43^{b}	0.00^{c}
A2B0C1	26.77	24.50^{c}	0.00^{g}	17.23	9.030^{c}	0.00^{c}	17.33	17.43^{b}	0.00^{c}
A3B0C0	26.77	3.67^{d}	0.00^{g}	17.23	8.320^{de}	0.00^{c}	17.33	17.42^{b}	0.00^{c}
A3B0C1	26.77	24.50^{c}	0.00^{g}	17.23	9.030^{c}	0.00^{c}	17.33	17.44^{b}	0.00^{c}
A0B1C0	26.77	3.98^{cd}	0.00^{g}	17.23	8.350^{de}	0.00^{c}	17.33	17.43^{b}	0.00^{c}
A0B1C1	26.77	28.17^{a}	0.00^{g}	17.23	9.220^{a}	6.19^{a}	17.33	17.46^{b}	21.17^{b}
A1^{b}1C0	26.77	3.98c^{d}	22.28^{de}	17.23	8.350^{de}	0.00^{c}	17.33	17.43^{b}	0.00^{c}
A1^{b}1C1	26.77	28.17^{a}	0.00^{g}	17.23	9.250^{a}	6.21^{a}	17.33	17.47^{b}	20.34^{b}
A2B1C0	26.77	3.99^{cd}	22.34^{abc}	17.23	8.350^{de}	0.00^{c}	17.33	17.44^{b}	0.00^{c}
A2B1C1	26.77	28.17^{a}	0.00^{g}	17.23	9.110^{b}	6.23^{a}	17.33	17.46^{b}	21.50^{b}
A3B1C0	26.77	3.99^{cd}	22.38^{ab}	17.23	9.020^{c}	0.00^{c}	17.33	17.43^{b}	0.00^{c}
A3^{b}1C1	26.77	28.18^{a}	0.00^{g}	17.23	9.230^{a}	6.23^{a}	17.33	17.47^{b}	20.60^{b}
A0B2C0	26.77	3.98^{cd}	22.27^{e}	17.23	8.320^{de}	0.00^{c}	17.33	17.42^{b}	0.00^{c}
A0B2C1	26.77	28.18^{a}	0.00^{g}	17.23	9.230^{a}	6.22^{a}	17.33	17.47^{b}	20.38^{b}
A1B2C0	26.77	3.98^{cd}	22.35^{abc}	17.23	8.307^{e}	0.00^{c}	17.33	17.43^{b}	0.00^{c}
A1B2C1	26.77	28.18^{a}	0.00^{g}	17.23	9.240^{a}	6.22^{a}	17.33	17.46^{b}	21.70^{b}
A2B2C0	26.77	3.98^{cd}	22.22^{h}	17.23	8.330^{de}	0.00^{c}	17.33	17.43^{b}	0.00^{c}
A2B2C1	26.77	28.18^{a}	0.00^{g}	17.23	9.220^{a}	6.21^{a}	17.33	17.47^{b}	21.23^{b}
A3B2C0	26.77	3.99^{cd}	22.38^{ab}	17.23	8.340^{de}	0.00^{c}	17.33	17.44^{b}	0.00^{c}
A3B2C1	26.77	28.19^{a}	0.00^{g}	17.23	9.260^{a}	6.22^{a}	17.33	17.46^{b}	20.97^{b}
A0^{b}3C0	26.77	3.98^{cd}	22.33^{cd}	17.23	8.320^{de}	0.00^{c}	17.33	17.42^{b}	0.00^{c}
A0B3C1	26.77	28.19^{a}	22.39^{a}	17.23	9.260^{a}	6.34^{a}	17.33	17.63^{a}	28.17^{a}
A1B3C0	26.77	28.18^{a}	22.35^{abc}	17.23	8.350^{de}	0.00^{c}	17.33	17.41^{b}	0.00^{c}
A1B3C1	26.77	5.38^{b}	22.33^{cd}	17.23	9.250^{a}	6.38^{a}	17.33	17.60^{a}	21.77^{b}
A2B3C0	26.77	3.98^{cd}	0.00^{g}	17.23	8.330^{de}	0.00^{c}	17.33	17.43^{b}	0.00^{c}
A2B3C1	26.77	28.18^{a}	22.33^{bc}	17.23	9.240^{a}	6.25^{a}	17.33	17.60^{a}	21.25^{b}
A3B3C0	26.77	3.98^{cd}	0.00^{g}	17.23	8.360^{d}	0.00^{c}	17.33	17.42^{b}	0.00^{c}
A3B3C1	26.77	3.98^{cd}	0.00^{g}	17.23	9.270^{a}	5.25^{b}	17.33	17.46^{b}	21.44^{b}
LSD (%)	-	**	**	-	**	**	-	*	**
CV (%)	-	1.82	0.27	-	0.38	13.46	-	0.35	20.13

Small letter in the same column differ significantly **Indicates significant level at 1% and *Indicates significant level at 5%

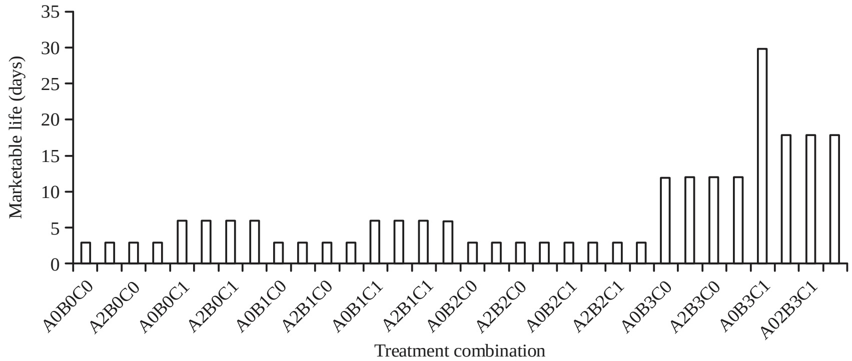

Fig. 5: Marketable life of litchi fruits stored under different storage conditions

Fig. 6(a-d): Marketable life and color of litchi fruits at (a) 0 day vs and (b, c, d)18 days

significant difference among the different treatments on the changes of TSS content of litchi fruit during storage of 12 and 30 days. At initial day of storage, TSS content was 17.33° Brix where it was 17.41-17.63° Brix and 20.34-28.17°Brix during 12 and 30 days of storage. The results indicated that TSS was increased with development of color and increasing storage periods. The results were in agreement with findings of Islam *et al.*[19] and Znidarcic and Pozrl[20].

Marketable life of litchi fruits during storage: The longest marketable life was recorded in fruits stored at 5±1°C (30 days more) compared to fruits stored at ambient condition. The lowest marketable life was recorded in fruits stored at open condition and without packaging under ambient condition (Fig. 5). In case of packaging, the highest marketable life (30 days more) with retention of good color was recorded in fruits kept in non-perforated polyethylene bag wrapping with newspaper under the temperature of 5±1°C (Fig. 6-8). However, the marketable life of litchi fruits significantly increased with decreasing storage temperature. These results are in agreement with the findings of Kalt *et al.*[21], where they had shown that low temperature and type of packaging material prolong the shelf life of the product.

Fig. 7(a-d): Marketable life and color of litchi fruits at (a) 0 day vs and (b, c, d) 30 days

Fig. 8(a-b): Packaging technique of litchi fruits

CONCLUSION

Litchi fruit stored in non-perforated polyethylene bag wrapping with browning paper (0.06 mm) significantly ($p<0.05$) delayed pericarp browning, inhibits PLW and decay loss, increased firmness, retained color and nutrition during storage at 5 ± 1°C in Bangladesh context. TSS increased with advancement of storage periods. Marketable life also significantly increased 30 days more using non-perforated polyethylene bag wrapping with browning paper (0.06 mm). Marketable life can be extended 40 days more by changing the wrapping materials in inside of the non-perforated polyethylene bag after 15 days interval although data is not putted in this study. This refrigerated temperature and simple packaging technique can apply in tropical and sub-tropical countries like Bangladesh as low cost technique. The consumers also may apply this simple and low cost technique at home scale level.

SIGNIFICANCE STATEMENTS

The study discovers the simple packaging technique as alternative of chemicals to control the pericarp browning, decay incidence, retain the color and maintain the overall quality of litchi fruit that can be beneficial for the litchi fruit growers, wholesalers, retailers and consumers. This study will help the researchers to uncover the technique for reducing enzymatic browning as well as minimization of postharvest loss of sub-tropical and tropical fruits.

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