PLANT SCIENCE TODAY
ISSN 2348-1900 (online)
Vol x(x): xx–xx
https://doi.org/10.14719/pst.6580

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RESEARCH ARTICLE

Impact of different treatments to enhance the fruit quality of litchi (*Litchi chinensis* Sonn.) cv. Bombai under stored temperature

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OPEN ACCESS

ARTICLE HISTORY
Received: 02 December 2024
Accepted: 05 February 2025
Available online
Version 1.0 : 24 March 2025

Check for updates

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

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Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
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CITE THIS ARTICLE
Balveer S, Ivi, Harsit S. Impact of different treatments to enhance the fruit quality of litchi (*Litchi chinensis* Sonn.) cv. Bombai under stored temperature. Plant Science Today (Early Access).
https://doi.org/10.14719/pst.6580

Abstract

Litchi (*Litchi chinensis*) is a delicious and juicy fruit. In India, it is cherished for its flavourful aril and consumed as a fresh table fruit, whereas, in China and Japan, it is often enjoyed in dried or canned form. The experiment was conducted in the Laboratory of Post-Harvest Technology of Horticultural Crops, Directorate of Research Complex, Bidhan Chandra Krishi Viswa Vidayalaya Kalyani, West Bengal, India. The objective of the study was to find out how to enhance the shelf life of litchi fruit after different treatments, stored in ambient and refrigerated temperatures. The fruits underwent various treatments, including sulphur fumigation, sulphur fumigation with sulphur padding, sulphur padding on the top side, sulphur padding on both sides, packaging in polypropylene, cover with litchi leaves and an untreated (control). These fruits were then packed in ventilated corrugated fibreboard (CFB) boxes, while some were also packed in perforated low-density polypropylene (LDPP) bags. The treated fruits were stored under ambient conditions (27 °C to 36 °C) and refrigerated conditions (10 ± 1 °C). All treated fruits were packed in perforated LDPP bags and stored in CFB boxes lined with sulphur padding on the top and sides. Over 16 days of storage, the fruits exhibited minimal weight loss, rotting and changes in total soluble solids, acidity, ascorbic acid and sugar (both reducing and total sugars). The fruit colour initially belonged to the Greyed Red Group 179A. After 16 days of refrigerated storage, fruits treated with sulphur padding on the top displayed a colour change to Red Group 45C, while those with sulphur padding on both sides and packed in perforated polypropylene within CFB boxes showed a shift to Greyed Red Group 181A. Under ambient conditions, the Greyed Red Group 179A colour was retained in fruits treated with sulphur padding on the top and both sides for up to 10 days. The minimum loss of peel anthocyanin was found in sulphur padding on the top side (6.56 and 7.05 mg/100 g) and sulphur padding on both sides (7.55 and 9.59 mg/100 g) of litchi fruits at refrigerated and ambient temperatures. The litchi fruit's cv. Bombai shelf life in both ambient and refrigerated settings found that sulphur padding on the top side of fruit packed in perforated polypropylene with a CFB box was successful in maintaining pericarp colour and quality by controlling spoiling by minimising browning and infections.

Keywords

packaging material; padding litchi; shelf life; sulphur fumigation

Introduction

Litchi (*Litchi chinensis* Sonn.), belonging to the family Sapindaceae, is an evergreen fruit tree native to South China. In India, major litchi growing states are Bihar, West Bengal, Assam and Jharkhand and to a smaller extent in Tripura, Punjab, Uttarakhand and Odisha. Litchi contains high levels of vitamin C (71.5 mg/100 g), which supports immune function and combats oxidative stress (1). In addition, litchi is an excellent source of niacin, folate, potassium and copper, all of which play vital roles in energy metabolism, cardiovascular health and cellular function (2). Quercetin and kaempferol, key flavonoids in litchi, have been associated with reduced risks of chronic diseases such as cardiovascular conditions and certain cancers (3). In West Bengal, India, the 'Bombai' cultivar is particularly esteemed for its large, obliquely heart-shaped fruits, carmine-red tubercles and juicy greyish - white pulp with a Total Soluble Solids (TSS) content of approximately 17 %, contributing to its rich flavour and market demand (4). Despite its popularity, litchi faces significant post-harvest challenges, particularly pericarp browning and microbial decay, which degrade its quality and marketability. Pericarp browning is primarily due to the oxidation of polyphenols, a process exacerbated by the fruit's high moisture content and susceptibility to desiccation, leading to rapid deterioration (5).

To mitigate these issues, sulfur dioxide (SO_2) fumigation has been a widely adopted method for reducing pericarp browning and extending shelf life. However, concerns about residual sulfite levels and their potential health risks have encouraged the exploration of alternative treatments (6). Recent studies indicate that combining SO_2 fumigation with low pH dips is effective in preserving pericarp colour and minimising decay, thus improving post-harvest quality (7). These advancements aim to enhance the fruit's shelf life and ensure it remains appealing and safe for consumers. The total soluble solids and titratable acidity are important factors in the assessment of flavour and nutrition of litchi fruit. Litchi fruit does not continue to ripen and accumulate sugars after harvest; therefore, TSS increases during fruit ripening, while the titrable acidity remarkably decreases. The litchi fruits are being utilised for preservation and processing for different products like canned litchi, squash, cordial, syrup, RTS (ready to serve), jam, jellies, juice and dried or dehydrated products (nuts) (8). Storage of litchi fruit at ambient temperature is problematic as it turns brown within two days. Sulphur dioxide controls browning by discolouration of the skin of litchi through the inhibition of PPO (9) and by combining with anthocyanin to form a more stable complex (10). Immediately after sulphur dioxide treatment, litchi fruit may appear as a uniform yellow colour and then turn red again after 1–2 days (11).

Generally, precooling after harvest and storage at low temperatures are one of the most prevalent methods for maintaining the appearance and quality of fruits (12). Litchi fruits are typically packed in plastic crates, fibreboard cartons or polystyrene boxes lined with polypropylene bags for export or long-distance transportation, whereas cardboard boxes and plastic crates are preferred for fruit export. Plastic bags reduce moisture loss from stored fruit over a broad temperature range (1-30°C) (13).

The quality standards for litchi ensure high-quality fruit that is safe for consumption and suitable for transportation. Litchis must be whole, sound, clean and free from pests, rot, abnormal moisture, foreign odours and significant damage. The fruit should be mature enough to endure handling and remain in good condition upon arrival. The classification of litchi is divided into three categories: "Extra" Class for superior fruit with minor superficial defects, Class I for good quality with slight imperfections in shape, colour or skin (up to 0.25 cm^2) and Class II for acceptable quality with more pronounced defects (up to 0.5 cm^2). Size is determined by the maximum equatorial diameter, with minimum sizes of 33 mm for "Extra" Class and 20 mm for Classes I and II, though all litchis must measure at least 15 mm. Packaging standards demand uniformity, clean materials and proper ventilation. Litchis may be presented individually with trimmed pedicels or in bunches with branches no longer than 15 cm. Compliance with contaminant and pesticide residue limits, along with hygienic handling, ensures food safety. These measures collectively maintain the fruit's high quality and transportability (14).

Materials and Methods

Experiment site

The present investigation was made in respect of the physico-chemical composition of litchi fruit, immediately after harvest collected from Horticulture Research Station at Mondouri, (BCKV), West Bengal, India. The experiment was conducted in the laboratory of Post-Harvest Technology of Horticultural Crops, Directorate of Research Complex, Bidhan Chandra Krishi Viswa Vidyalaya Kalyani, West Bengal, India. Good quality fruits free from disease and pest attack were sorted out for conducting the storage experiment.

Traits studied

The colour and texture of the fruit were recorded by the Royal Horticulture Society colour chart. The rotting of litchi fruit was determined according to colour and flavours while browning content was determined after centrifuge by spectrophotometric method. Total soluble solids (TSS) were estimated using a pocket refractometer. The titratable acidity was determined by titrating against 0.1 N NaOH and expressed as anhydrous citric acid and the ascorbic acid (mg/100 g) content of fruit was determined by using 2, 6 dichlorophenol-indophenol dye by visual titration method (15). Reducing sugars and total sugar content of the fruits were estimated following the standard method described (15). The anthocyanin content of the peel was estimated by the spectrophotometric method using Mecasys Optizen Pop Spectrophotometer following the procedure expressed (15) after extraction with methanolic HCl at 535 nm and presented as mg/100 g peel.

Treatments Details

Five-hundred gram fruit samples were taken for the following treatment combinations.

Treatment	Treatment Description	Packaging Material	Additional Features
T_1	SO_2 fumigation for 5 minutes	Perforated low-density polypropylene (LDPP) packet	1 g potassium metabisulfite and 1 ml hydro sulphuric acid placed in a desiccator for 5 minutes
T_2	SO_2 fumigation for 5 minutes and sulphur padding on the top side	Perforated low-density polypropylene (LDPP) packet	Same as T_1 with additional sulphur padding on the top side of the LDPP packet
T_3	Sulphur padding on the top side of the fruit	Perforated low-density polypropylene (LDPP) packet	Sulphur padding placed only on the top side of the LDPP packet
T_4	Sulphur padding on the top and bottom sides of the fruit	Perforated low-density polypropylene (LDPP) packet	Sulphur padding placed on the top and bottom sides of the LDPP packet
T_5	Packing without SO_2 fumigation and sulphur padding	Perforated low-density polypropylene (LDPP) packet	-
T_6	Packing with litchi leaves on the top and bottom sides of the fruits	Perforated low-density polypropylene (LDPP) packet	Litchi leaves placed on the top and bottom sides of the LDPP packet
T_7	Control	-	-

All treated fruits were packed in corrugated fibreboard (CFB) boxes for storage at ambient and refrigerated temperatures.

Statistical analysis

The experiment was laid out with seven treatments and three replications, consisting of 500 grams of fruits in each replication. The statistical analysis of the data was done by the previously described method (16) using a completely randomised block design (CRD).

Results and Discussion

Changes in physiological loss in weight (%)

The data recorded on changes in physiological loss in weight of litchi fruit during storage is presented in Table 1. The per cent physiological loss in weight of different treatments was significantly increased during storage under each treatment. The minimum physiological loss in weight was found in sulphur padding on the top side of fruit packed in perforated polypropylene with CFB box (3.91 %) followed by sulphur padding on both sides of fruit packed in perforated polypropylene with CFB box (3.92 %) after 16 days of storage in refrigerated, while control was maximum weight loss (11.91 %) after 14 days. The same treatment was observed in ambient temperature. The minimum weight loss was showed in sulphur padding on the top side of fruit packed in perforated polypropylene with CFB box (4.93 %) followed by sulphur padding on both sides of fruit packed in perforated polypropylene with CFB box (5.90 %) after 10 days, while control (10.80 %) was maximum loss after 4 days of storage. The reduction in weight is attributed to the physiological loss in weight (PLW) due to respiration, transpiration of water through peel tissue and other biological changes taking place in the fruit (17). Another reason is application of SO_2 fumigation intensified the extent of microcracking in litchi (18). The spongy tissue responsible for gas exchange in the pericarp was thought to be responsible for water loss. The same result was also recorded in litchi cv. Mauritius (19) and in cv. Kom (20).

Changes in colour

The colour of the fruit was taken on the basis of the Royal Horticulture Society colour chart in Table 1. Fruit colours were Greyed red group 179 A at the initial stage of the storage (Fig. 1). Colour change started after 2 days in all treatments during storage in refrigerated and ambient temperatures. Changes in colour started faster under ambient temperature than under refrigerated temperature. In sulphur padding on the top side of the fruit packed in perforated polypropylene with CFB box and sulphur padding on both sides of the fruit packed in perforated polypropylene with CFB box showed slower colour changes as compared to the other treatment in both conditions. After 14 days of storage, SO_2 fumigation for 5 minutes with perforated polypropylene (Red group 45C) and SO_2 fumigation for 5 min with sulphur padding at the top side with perforated polypropylene (Orange red group 35C) were packed in perforated polypropylene packet and covered with litchi leaves at the top and bottom of fruits (Greyed red group 180A). The control (Greyed red 178A) had padding on the top side of the fruit packed in perforated polypropylene with CFB box (Red group 45C) and sulphur padding at both sides of polypropylene of fruits (Greyed red group 181A). The colour changes were observed after 16 days of storage.

Fruit colour in ambient condition after 4 days was found to be Greyed red group 179A in 5 min-SO_2 fumigated with perforated polypropylene and Greyed red 177A in packed, perforated polypropylene packet, covered with litchi leaves at the top and bottom of fruits. In control, 5 minutes-SO_2 fumigated and Sulphur padding at the top side with perforated polypropylene, packed in a perforated polypropylene packet remained the same as refrigerated temperature. But in the sulphur padding on the top side of the fruit packed in perforated polypropylene with CFB box and sulphur padding on both sides of the fruit packed in perforated polypropylene with CFB box showed Greyed red group 179A after 10 days of storage.

The causes of colour degradation by blanching or dehydration were earlier reported (21) with browning reactions, active polyphenol oxidase and peroxidase (22) and the existence of other anthocyanin-related compounds present in the pericarp (23, 24).

Fruit rotting (%)

The effect of different treatments and rotting of fruits in corrugated fibre board boxes is presented in Table 2. From the data, it is evident that there was no rotting of fruit for up to 8 days of storage at refrigerated temperature but in ambient temperature rotting started from 2 days onward. The rotting of fruit increased throughout the storage period and significantly higher rotting was observed on the last day of storage (Fig. 2 and Fig. 3). Data showed that there was

Table 1. Effect of different treatments on physiological loss in weight (%) and colour of litchi fruit during storage at refrigerated temperature ambient temperature

Treatment	Physiological loss in weight (%) – Refrigerated temperature (10±1°C) 2 days	4 days	6 days	8 days	10 days	12 days	14 days	16 days	Ambient temperature 2 days	4 days	6 days	8 days	10 days
T_1	0.91	0.95	1.79	1.93	2.91	3.88	5.89	-	1.93	2.74			
T_2	0.93	0.95	1.82	2.92	4.86	5.92	7.93	-	2.75	3.84			
T_3	00	0.19	0.82	0.95	2.15	1.93	2.89	3.91	2.64	3.31	3.94	4.27	4.93
T_4	00	0.76	0.86	0.90	2.94	2.94	3.87	3.92	3.81	4.23	4.84	5.67	5.90
T_5	0.93	1.89	2.96	3.91	4.92	7.85	9.88	-	3.84	5.90			
T_6	0.90	1.86	2.94	5.93	6.92	7.85	7.85	-	4.92	5.67			
T_7	1.86	3.85	5.93	6.87	7.88	9.92	11.91	-	4.95	10.8			
SE (m)	0.022	0.063	0.065	0.029	0.061	0.021	0.027	0.006	0.075	0.080	0.016	0.026	0.008
CD	0.066	0.193	0.200	0.088	0.186	0.064	0.083	0.019	0.230	0.246	0.050	0.081	0.024
CV	4.829	7.313	4.631	1.495	2.257	0.630	0.658	0.754	3.663	2.666	2.270	3.221	0.892

Treatment	Colour – Refrigerated temperature (10±1°C) 2 days	4 days	6 days	8 days	10 days	12 days	14 days	16 days	Ambient temperature 2 days	4 days	6 days	8 days	10 days
T_1	Yellow group 8 B	Yellow group 8 B	Greyed orange group 164 B	Greyed orange group 164 B	Greyed orange group 164 A	Red group 45 C	Red group 45 C	-	Yellow group 8 B	Greyed red group 179A			
T_2	Orange red group 35 D	Orange red group 35 D	Orange red group 35 C	Greyed orange group 165 C	Greyed orange group 165 C	Orange red group 35 C	Orange red group 35 C	-	Yellow group 8 B	Orange red group 35 C			
T_3	Red group 43 B	Red group 43 B	Greyed red group 179 B	Greyed red group 179 A	Greyed red group 179 A	Red group 45 D	Red group 45 D	Red group 45 C	Red group 43 B	Greyed red group 179 B	Greyed red group 179A	Greyed red group 179A	Greyed red group 179A
T_4	Greyed red group 178 B	Greyed red group 178 A	Greyed red group 178 A	Greyed red group 179 B	Greyed red group 179 B	Greyed red group 181 B	Greyed red group 181 A	Greyed red group 181 A	Greyed red group 178 A	Greyed red group 178 A	Greyed red group 179 C	Greyed red group 179 C	Greyed red group 179 A
T_5	Greyed orange group 165 C	Greyed orange group 165 B	Greyed orange group 165 A	Greyed orange group 165 A	Greyed red group 179 B	Greyed red group 180 B	Greyed red group 180 A	-	Greyed orange group 177A	Greyed red 178 A			
T_6	Greyed red group 179A	Greyed red group 178 D	Greyed red group 178 D	Greyed red group 178 C	Greyed red group 180 B	Greyed red group 180 B	Greyed red group 180 A	-	Greyed red 178 B	Greyed red 177 A			
T_7	Greyed orange group 177C	Greyed orange group 177 B	Greyed orange group 177A	Greyed orange group 177A	Greyed red group 177 B	Greyed red 177 A	Greyed red 178 A	-	Greyed red 177 A	Greyed red 177 A			

Fig. 1. Zero day of different treatments of litchi fruit.

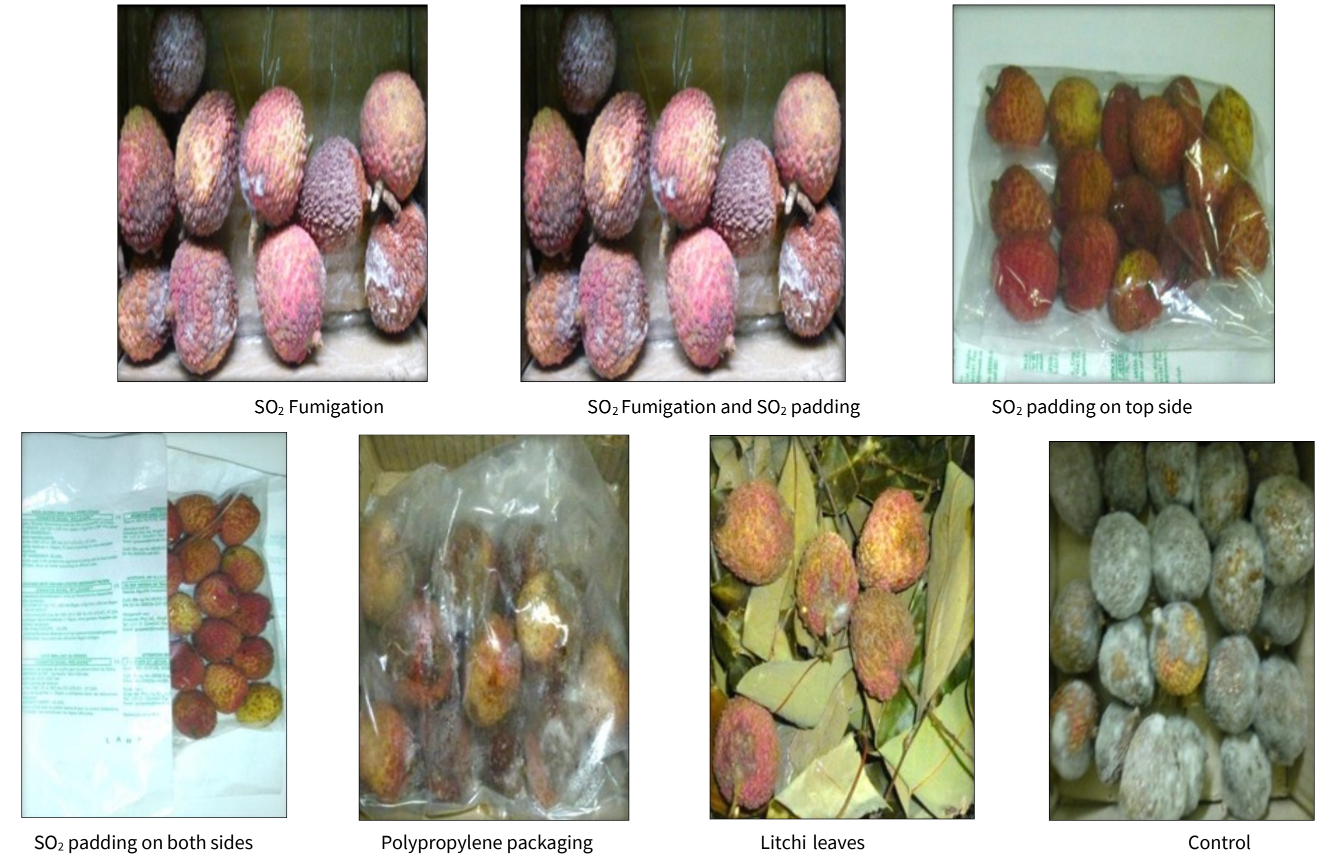

Fig. 2. After ten days at ambient temperature.

Fig. 3. After ten days of refrigerated storage.

more rotting at ambient temperature than at low temperature. In general, litchi had an increasing trend of average rotting from 6.66 to 43.33 % on 16 days of storage with different treatments at refrigerated temperature and 8.33 to 39.00 % on 10 days of storage at ambient temperature. The minimum rotting was found in sulphur padding on the top side of the fruit packed in perforated polypropylene with CFB box and sulphur padding on both sides of the fruit packed in perforated polypropylene with CFB box at 26.67 and 29.17 % after 16 days of storage at refrigerated temperature and 30.66 and 39.00 % after 10 days at ambient temperature, respectively, during storage. Maximum rotting was found in control at 43.33 and 41.66 % after 14 days and 4 days, respectively, during storage at refrigerated and ambient temperatures. A wide range of fungi can cause decay of litchi fruit (25, 26). This may be the reason behind the rotting of litchi fruits in the treatments. The organisms which have been associated with rotting are Penicillium, Aspergillus, Rhizopus, Fusarium, Colletotrichum, Botryodiplodia, Pestalotiopsis, Phomopsis and Alternaria (27).

Changing in browning

Data pertaining to the browning (Optical Density) of litchi fruits during storage are presented in Table 2. Browning (OD) increased gradually with the increase in storage period in each treatment. The rate of browning of fruits was more rapid at ambient temperature than at refrigerated temperature. The initial stage of browning was 0.014–0.037 and after 16 days of storage of fruits, the significant minimum changes of browning was in the top side-sulphur padded fruit packed with perforated polypropylene in CFB box (0.164) followed by sulphur padding both side of fruit packed in perforated polypropylene with CFB box (0.167) compared to other treatment. The highest browning index was observed in untreated fruits in the control condition (0.669) after 14 days of storage. A similar trend was observed in ambient temperature also. The lowest browning was found in the top side-sulphur padded fruit packed with perforated polypropylene in the CFB box (0.165) and both sides-sulphur padded fruit packed with perforated polypropylene in the CFB box (0.392) after 10 days, while control exhibited maximum browning (0.335) after 4 days of storage. Keeping litchi at a low temperature is essential in delaying fruit browning because it slows down respiration (28, 29). Prevention of browning by packaging litchi in various PE materials seemed to be due to the effect of maintaining high humidity and low oxygen atmosphere in the package (30).

Changes in total soluble solids (°Brix)

The changes in total soluble solids data are presented in Table 3. The total soluble solids (°Brix) of all treated fruit were decreased during storage under refrigerated and ambient temperatures. The total soluble solids in °Brix gradually decreased significantly up to 14 days of storage and gradually till the end of the storage period. However, treated sulphur padding on both sides of the fruit packed in perforated polypropylene with CFB box retained a maximum of 14.8 °Brix followed by sulphur padding on the top side of fruit packed in perforated polypropylene with CFB box (14.00 °Brix TSS) after 16 days of storage while minimum total soluble solids was recorded in control (13.90 °Brix) after 14 days of storage. The TSS value of fruit was rapidly decreased at ambient temperature compared to refrigerated temperature. The fruit kept in sulphur padding on both sides of the fruit packed in perforated polypropylene with CFB box and sulphur padding top side of the fruit packed in perforated polypropylene with CFB box retained the highest TSS content of 13.2 and 12.7 °Brix after 10 days of storage at ambient temperatures, respectively. Changes in total soluble solids are due to the consumption of sugar for respiration and the utilisation of sugars for the growth of microbes (31). TSS increases with the development of colour and increasing storage periods (32).

Changes in titratable acidity (%)

The data on the changes in titratable acidity is presented in Table 3. Titratable acidity was gradually decreased during storage at both temperatures. A similar decrease in acidity was observed in all treated fruits till 14 days of storage but in sulphur padding on both sides of the fruit packed in perforated polypropylene with CFB box and sulphur padding on top side of fruit packed in perforated polypropylene with CFB box was found to be 0.13 % on 16 days at refrigerated storage. At ambient temperature, TTA was rapidly decreased during storage. In sulphur padding on both sides of the fruit packed in perforated polypropylene with CFB box and sulphur padding on the top side of the fruit packed in perforated polypropylene with CFB box a similar decrease in acidity was noticed after 10 days of storage. Litchi fruits are highly sensitive to water loss during storage, which can occur due to high respiration rates or poor storage conditions. As the fruit loses moisture, the concentration of soluble sugars increases. While the concentration of sugars increases, the decline in the overall moisture content may lead to a relative decrease in the concentration of organic acids. This contributes to the apparent reduction in titrable acidity (33).

Changes in ascorbic acid (mg/100 g)

Ascorbic acid reduced during storage at both temperatures is reported in Table 4. The highest ascorbic acid was reported in sulphur padding on the top side of the fruit packed in perforated polypropylene with CFB box (6.90 mg/100 g) followed by sulphur padding on both sides of the fruit packed

Table 2. Effect of different treatments on rotting (%) and browning during storage at refrigerated temperature and ambient temperature

Treatment	Rotting (%)													Browning (%)												
	Refrigerated temperature (10±1°C)								Ambient temperature					Refrigerated temperature (10±1°C)								Ambient temperature				
	2 days	4 days	6 days	8 days	10 days	12 days	14 days	16 days	2 days	4 days	6 days	8 days	10 days	2 days	4 days	6 days	8 days	10 days	12 days	14 days	16 days	2 days	4 days	6 days	8 days	10 days
T_1	0	0	0	0	11.66	20	30.83	-	19.33	37.66				0.031	0.039	0.048	0.055	0.117	0.119	0.536	-	0.056	0.113			
T_2	0	0	0	0	16.66	23.33	35.83	-	19.00	33.16				0.023	0.035	0.050	0.088	0.093	0.101	0.506	-	0.061	0.121			
T_3	0	0	0	0	6.66	10	18.33	26.67	8.33	18.33	19.33	21.66	30.66	0.037	0.038	0.044	0.094	0.081	0.092	0.124	0.164	0.054	0.063	0.075	0.124	0.165
T_4	0	0	0	0	11.66	23.33	23.33	29.17	14.33	25.33	25.00	28.66	39.00	0.031	0.041	0.082	0.092	0.099	0.117	0.123	0.167	0.045	0.051	0.107	0.201	0.392
T_5	0	0	0	0	18.33	21.67	30.83	-	20.00	34.83				0.027	0.033	0.053	0.054	0.096	0.329	0.430	-	0.032	0.130			
T_6	0	0	0	0	18.33	28.33	34.16	-	19.66	38.00				0.028	0.052	0.079	0.085	0.087	0.093	0.321	-	0.048	0.193			
T_7	0	0	0	0	11.66	20	43.33	-	20.66	41.00				0.014	0.046	0.050	0.065	0.072	0.073	0.669	-	0.072	0.335			
SE (m)					0.591	1.260	1.347	0.445	0.678	0.986	0.471	0.882	0.850	0.001	0.002	0.001	0.107	0.001	0.040	0.001	0.001	0.001	0.001	0.003	0.002	0.002
CD					1.810	3.858	4.125	1.364	2.078	3.020	1.901	3.556	3.426	0.004	0.005	0.003	NS	0.003	NS	0.002	0.003	0.002	0.003	0.010	0.006	0.006
CV					6.592	10.145	7.538	9.673	6.780	5.236	3.683	6.070	4.226	7.587	6.653	3.143	8.757	1.831	6.638	0.324	0.652	1.897	1.157	4.786	1.702	0.950

Table 3. Effect of different treatments on total soluble solids (ºBrix) and titratable acidity (%) during storage at refrigerated temperature and ambient temperature

Treatment	Total soluble solids (°Brix)													Titratable acidity (%)												
	Refrigerated temperature (10±1°C)								Ambient temperature					Refrigerated temperature (10±1°C)								Ambient temperature				
	2 days	4 days	6 days	8 days	10 days	12 days	14 days	16 days	2 days	4 days	6 days	8 days	10 days	2 days	4 days	6 days	8 days	10 days	12 days	14 days	16 days	2 days	4 days	6 days	8 days	10 days
T_1	16.4	16	15.5	15.2	14.8	14.7	14.6		15.2	14.7	-	-	-	0.38	0.29	0.26	0.19	0.16	0.13	0.13	-	0.32	0.22	-	-	-
T_2	16.4	15.8	15.4	15	15	14.5	14.2	-	15	14.5	-	-	-	0.32	0.26	0.19	0.19	0.18	0.16	0.13	-	0.22	0.16	-	-	-
T_3	16.5	16.4	16	15.4	14.6	14.2	14.2	14	15.4	15.5	14.6	13.5	13.2	0.32	0.26	0.19	0.18	0.16	0.16	0.16	0.13	0.19	0.19	0.19	0.16	0.12
T_4	16	16	16	16	15.7	15.6	14.8	14.8	16	15.8	15	13.8	12.7	0.22	0.16	0.16	0.16	0.16	0.15	0.13	0.13	0.19	0.16	0.16	0.15	0.12
T_5	16.4	16.2	15.9	15.9	15.7	14.6	14.2	-	14	13.9	-	-	-	0.38	0.26	0.26	0.16	0.16	0.13	0.13	-	0.22	0.16	-	-	-
T_6	16.5	16	15.8	15.5	15.3	14.8	14.3	-	14.4	13	-	-	-	0.26	0.22	0.19	0.19	0.16	0.16	0.13	-	0.16	0.13	-	-	-
T_7	16.8	16.6	16.3	15.1	14.7	14.3	13.9	-	14.7	14.4	-	-	-	0.22	0.19	0.19	0.16	0.16	0.13	0.13	-	0.19	0.16	-	-	-
SE (m)	0.248	0.248	0.238	0.237	0.228	0.222	0.208	0.098	0.151	0.110	0.069	0.049	0.053	0.005	0.003	0.003	0.002	0.002	0.001	0.001	0.002	0.004	0.002	0.003	0.002	0.003
CD	NS	NS	NS	NS	0.699	0.679	NS	0.299	0.463	0.336	0.211	0.149	0.164	0.015	0.010	0.009	0.007	0.004	0.004	0.004	0.005	0.011	0.007	0.005	0.005	0.009
CV	2.616	2.662	2.605	2.659	2.616	2.620	2.516	4.108	1.749	1.308	2.827	2.167	2.502	2.905	2.454	2.372	2.145	1.895	1.493	1.619	1.978	2.900	2.236	2.636	1.979	15.590

in perforated polypropylene with CFB box (5.20 mg/100 g) after 16 days of storage at refrigerated temperature. At ambient temperature, all treated and untreated fruit contained a lower amount of ascorbic acid as compared to refrigerated temperature. The maximum vitamin C content was recorded in the sulphur padding on the top side of the fruit packed in perforated polypropylene with CFB box (23.60 mg/100 g) followed by sulphur padding on both sides of the fruit packed in perforated polypropylene with CFB box (15.20 mg/100 g) after 10 days and lowest in SO_2 fumigation for 5 min with perforated polypropylene (11.20 mg/100 g) after 4 days during storage. The ascorbic acid content decreased with prolonged storage time at low temperatures. The fruit stored for 30 days consequently had much lower ascorbic acid content over shelf time at 25 ºC than fruit cold-stored for 10 or 20 days (36). The loss of ascorbic acid during storage may be ascribed to its higher oxidation rate, which consequently increases its degradation and browning (34, 35).

Changes in reducing sugar (%)

The reducing sugar content of treated and untreated litchi fruit is reported in Table 4. Reducing sugar was decreased in both types of storage. The maximum reducing sugar was found in sulphur padding on both sides of fruit packed in perforated polypropylene with CFB box (8.29 %) followed by sulphur padding on the top side of fruit packed in perforated polypropylene with CFB box (8.12 %) after 16 days of storage, while minimum in control (8.32 %) after 14 days of storage at refrigeration condition. The rate of decrease in reducing sugar was observed more in ambient temperature than at low temperature. The minimum reducing sugar was observed in the top side-sulphur padded fruit packed in perforated polypropylene with CFB box (7.96 %) followed by both side-sulphur padded fruit packed in perforated polypropylene with CFB box (8.00 %) after 10 days of storage, while in control (9.50 %) after 4 days of storage at ambient temperature. Reducing and total sugar was significantly higher in fruit stored at 5 ± 1 °C under different packaging techniques than the fruit stored at ambient conditions. Reducing and total sugars were positively correlated to TA and pH under the fruit stored at 5 ± 1 °C than ambient temperature (36, 37).

Changes in total sugar (%)

It is evident from Table 5 that the total sugar content of the litchi cultivar Bombai decreased continuously during the entire period of storage in refrigerated and ambient temperatures. Among the different treatments, fruits kept in sulphur padding on the top side of fruit packed in perforated polypropylene with CFB box and sulphur padding on both sides of fruit packed in perforated polypropylene with CFB box exhibited the same total sugar content (10.53 %) after 16 days of storage at refrigerated temperature. A similar trend was observed in ambient conditions. Like only these two treatments (sulphur padding on the top side of fruit packed in perforated polypropylene with CFB box and sulphur padding on both sides of fruit packed in perforated polypropylene with CFB box) kept litchi fruits in good condition for up to 10 days at ambient condition whereas fruits under rest other treatments were rotten within 4-5 days. The decrease in total sugar levels could be caused by the sugars' participation in browning events that produce hydroxymethyl furfural and by the hydrolysis of sugars by acids, which turns them into monosaccharides. In galgal juice concentrate, a similar pattern was noted (38).

Changes in anthocyanin (mg/100 g)

Data pertaining to anthocyanin of litchi fruit during storage is presented in Table 5. The level of anthocyanin content decreased gradually in the storage period of both temperatures. From the table, it is revealed that the anthocyanin content of sulphur padding on both sides of fruit packed in perforated polypropylene with CFB box (7.55 mg/100 g) was significantly highest followed by sulphur padding on the top side of fruit packed in perforated polypropylene with CFB box (6.56 mg/100 g) after 16 days of storage while minimum was observed in control (5.95 mg/100 g) after 14 days of storage at refrigerated temperature. The highest decrease in anthocyanin content was noticed at room temperature compared to cold temperature. The maximum anthocyanin content was found (9.59 mg/100 g) in sulphur padding on both sides of fruit packed in perforated polypropylene with CFB box after 10 days while the minimum was reported in control (7.31 mg/100 g) after 4 days of storage. Anthocyanin degradation in the pericarp took place rapidly in fruits harvested at 102 days after blossom, during the five days of storage at room temperature. Three days after harvest, pericarp anthocyanin content had decreased by 8 %; however, between the third and fifth day, its concentration had reduced by 36 % (39).

Table 4. Effect of different treatments on ascorbic acid (mg/100 g) and reducing sugar (%) during storage at refrigerated temperature and ambient temperature

Treatment	Ascorbic acid (mg/100g)													Reducing sugar (%)												
	Refrigerated temperature (10±1°C)								Ambient temperature					Refrigerated temperature (10±1°C)								Ambient temperature				
	2 days	4 days	6 days	8 days	10 days	12 days	14 days	16 days	2 days	4 days	6 days	8 days	10 days	2 days	4 days	6 days	8 days	10 days	12 days	14 days	16 days	2 days	4 days	6 days	8 days	10 days
T_1	54.0	30.0	24.0	16.0	10.2	8.4	5.71	-	48.00	11.20	-	-	-	10.76	10.53	10.11	10	9.67	9.5	8.76	-	10.39	9.5	-	-	-
T_2	57.6	50.0	36.4	24.0	15.4	10.6	8.40	-	51.20	48.00	-	-	-	10.81	10.76	10.39	9.76	9.38	9.16	8.35	-	10.63	9.52	-	-	-
T_3	43.2	34.0	32.0	24.0	16.1	10.0	5.60	5.20	54.40	51.20	33.60	25.60	15.20	11.11	10.76	10.53	10.11	10	9.52	9.28	8.12	11.38	10.76	9.5	8.59	7.96
T_4	52.0	38.4	36.8	23.8	19.6	12.0	7.00	6.90	54.40	48.00	38.40	30.80	23.60	10.76	10.72	10.63	10.33	9.96	9.5	8.59	8.29	11.11	10	9.96	9.5	8
T_5	51.2	46.4	36.0	21.0	14.0	9.5	7.00	-	33.60	21.00	-	-	-	10.76	10.53	10.29	9.96	9.45	9.24	8.84	-	10.32	9.72	-	-	-
T_6	51.4	43.2	38.4	25.8	21.0	15.3	8.40	-	32.00	23.80	-	-	-	11.11	10.76	10.11	9.78	9.51	9.23	8.47	-	11.38	10.7	-	-	-
T_7	52.7	48.0	34.0	23.9	14.0	10.6	7.00	-	36.80	25.80	-	-	-	10.72	10.76	10.53	9.76	9.36	8.63	8.32	-	10	9.5	-	-	-
SE (m)	0.773	0.609	0.510	0.350	0.241	0.160	0.106	0.044	0.725	0.583	0.260	0.193	0.140	0.169	0.157	0.153	0.135	0.139	0.146	0.127	0.068	0.169	0.155	0.073	0.064	0.059
CD	2.366	1.866	1.563	1.071	2.647	0.491	0.325	0.134	2.219	1.786	0.796	0.590	0.428	NS	NS	NS	NS	0.426	0.447	0.388	0.208	0.519	0.476	0.225	0.197	0.181
CV	2.587	2.547	2.604	2.673	2.647	2.548	2.618	4.373	2.831	3.082	4.375	4.147	4.364	2.688	2.542	2.563	2.481	2.506	2.732	2.533	5.016	2.732	2.702	4.575	4.319	4.489

Table 5. Effect of different treatments on total sugar (%) and anthocyanin (mg/100 g) during storage at refrigerated temperature and ambient temperature

Treatment	Total sugar (%)													Anthocyanin (mg/100g)												
	Refrigerated temperature (10±1°C)								Ambient temperature					Refrigerated temperature (10±1°C)								Ambient temperature				
	2 days	4 days	6 days	8 days	10 days	12 days	14 days	16 days	2 days	4 days	6 days	8 days	10 days	2 days	4 days	6 days	8 days	10 days	12 days	14 days	16 days	2 days	4 days	6 days	8 days	10 days
T_1	12.67	12.38	11.67	11.67	11.45	11.18	10.29	-	13.33	11.76	-	-	-	18.56	16.61	16.13	13.30	11.99	11.07	10.23		16.44	15.05			-
T_2	12.33	12.29	11.38	11.11	10.67	10.38	10.16	-	13.33	12.5	-	-	-	18.49	16.34	15.12	11.08	10.43	7.48	6.09		17.23	16.76			
T_3	12.67	12.5	12.38	12.38	11.76	11.76	11.38	10.53	12.5	11.38	11.11	11	9.52	17.46	16.42	15.30	13.87	11.67	9.14	7.41	6.56	16.80	16.29	11.95	9.89	7.05
T_4	13.33	12.5	12.38	12.29	11.76	11.38	11.38	10.53	13.33	12.5	12	11.38	10	18.41	17.23	15.78	14.42	12.60	9.54	8.96	7.55	16.83	16.33	13.97	11.34	9.59
T_5	13.33	12.29	12.18	11.76	11.29	11.18	10.67	-	11.76	10	-	-	-	16.34	14.63	14.38	12.72	9.74	9.58	8.25		17.30	16.94			-
T_6	12.5	12.38	12.29	11.53	11.38	10.38	10.29	-	13.33	12.5	-	-	-	16.13	16.13	13.55	11.07	9.97	8.80	6.85		10.70	7.50			
T_7	13.33	12.67	12.5	11.38	10.76	10.38	10.33	-	12.5	11.76	-	-	-	16.34	15.12	12.55	10.83	8.80	7.56	5.95		10.60	7.31			-
SE (m)	0.195	0.189	0.183	0.183	0.171	0.155	0.152	0.073	0.185	0.168	0.082	0.082	0.067	0.263	0.249	0.219	0.194	0.165	0.133	0.115	0.056	0.234	0.209	0.097	0.080	0.064
CD	0.598	NS	0.562	0.562	0.523	0.474	0.465	0.225	0.567	0.513	0.250	0.250	0.204	0.807	0.763	0.669	0.593	0.506	0.408	0.352	0.173	0.717	0.641	0.296	0.244	0.197
CV	2.626	2.641	2.625	2.709	2.624	2.449	2.468	4.228	2.494	2.466	4.285	4.419	4.138	2.622	2.689	2.577	2.689	2.662	2.557	2.587	4.845	2.681	2.637	4.530	4.550	4.683

Conclusion

This study on the storage life of fresh litchi fruit cv. Bombai concludes that sulphur padding on the top side of fruit packed in perforated polypropylene with CFB box proved effective in the maintenance of pericarp colour and quality through control of spoilage by minimising browning and diseases under both temperatures. The sulphur padding on the top side of the fruit packed in perforated polypropylene with CFB box maintained all the quality parameters followed by sulphur padding on both sides of fruit packed in perforated polypropylene with CFB box such as minimum PLW loss, browning and rotting, higher TSS, acidity, ascorbic acid, sugar and anthocyanin content than other treatments at the end of the storage period. Future research should explore the potential of novel, environment-friendly post-harvest treatments and advanced packaging techniques to further extend the shelf life of litchi. Additionally, investigations into the interplay between storage conditions, including temperature and humidity and their impact on quality preservation, microbial inhibition and phytochemical stability will be crucial for optimising post-harvest handling practices.

Acknowledgements

The authors are grateful for the financial help provided by the Department of Post Harvest Management, BCKV, Mohanpur, Nadia (WB).

Authors' contributions

BS carried out the work of data recording, statistical analysis and writing the original draft. IC carried out the work of conceptualisation, guidance and data finalisation. HS carried out the work of manuscript writing, reviewing and editing.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests.

Ethical issues: None

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