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Research article

Effects of packaging and duration on quality of minimally processed and unpitted litchi cv. 'Mauritius' under low storage temperature

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ABSTRACT

Pericarp drying is a major postharvest challenge affecting the shelf life of litchi fruit resulting in loss of market value and consumer rejection. Sulphur dioxide (SO_2) is considered an allergen due to its ability to cause irritation in people, particularly those vulnerable to asthma. Thus, the objective of this study was to investigate the effects of packaging and storage duration without SO_2 on the quality attributes of minimally processed litchi fruit cv. 'Mauritus'. Minimally processed litchi cv. 'Mauritius' were packed inside clamshell trays with different perforation sizes: 0 (P-0), 1.1 mm (P-1), and 5.4 mm (P-2) and stored at 1 °C for 15 days, and then held at 12 °C for 2 days for shelf life study (mimicking retail practices). The least mass loss % was observed in fruit packaged under P-0 followed by P-1 and P-2 until the end of storage. Fruit packed in P-2 (5.4 mm perforation) had the highest firmness compared to samples from other packages, but, they also had the highest decay incidences at day 9. The TSS (°Brix) was highest in fruit packed under P-0 followed by P-2 than P-1 at the end of storage. The TSS:TA increased significantly with storage duration with highest value obtained on day 9 in P-0 (121.63) in comparison to P-1 (108.44) and P-2 (103.35). Ascorbic acid and radical scavenging activity declined with prolonged storage irrespective of package type. Overall litchi fruit were better maintained in non-perforated and 1.1 mm perforated clamshell trays up to 9 days, without decay incidences.

1. Introduction

Litchi (*Litchi chinensis* Sonn.) is tropical and subtropical crop belonging to the *Sapindaceae* family. Litchi fruit is widely grown in countries including South Africa, China, Israel, Madagascar, Mauritius, USA, Indonesia, India, the Philippines, Taiwan, Thailand Australia, Brazil and Vietnam (Menzel, 2001; Lemmer, 2002; Huang et al., 2005). Litchi fruit is mostly desired by consumers for its sweet/exotic taste, easy to peel and attractive red color. It is a rich source of phenolic compounds and vitamin C (Wall, 2006). The fruit has a rough indehiscent pericarp covering the edible aril and the seed in the centre. Litchi is non-climacteric fruit, and it is only harvested when fully matured. After harvest, fruit are stored in the temperatures ranging between -1 and 7 °C for 20 to 30 days (Gross et al., 2002). However, postharvest challenges including micro-cracking, pericarp browning, dehydration, loss of quality and decay limits the fruit and flavor quality during storage, transportation or shelf life (Tian et al., 2005; Sivakumar et al., 2007; Holcroft and Mitcham, 1996). In addition, incorrect postharvest handling practices during the cold chains could also accelerate desiccation and moisture loss, which lead to intensive pericarp browning. Although, pericarp browning has been shown not to affect the sensory quality of litchi fruit (Mangaraj and Goswami, 2011), but, this defect influences consumers' preference and decision to purchase the fruit.

Furthermore, litchi fruit pericarp is relatively thin and lacks a thick, durable cuticle. Thus, fruit desiccation is a major challenge during postharvest storage life. As a result of desiccation, litchi fruit rapidly loose colour. Unless treated immediately after harvest, it will turn into an unattractive brown colour (Kaiser et al., 1994). In order to prolong the shelf life of litchi fruit, sulphur dioxide (SO_2) fumigation is widely used to maintain the red color and prevent postharvest decay. However, sulphur treatment has become undesirable due to its effects on the health of certain consumers. The presence of sulphite could trigger asthmatic

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reactions and other allergic reactions when ingested by sensitive individuals (Koeing et al., 1983). Sulphur dioxide is regarded as allergen due to its ability to cause irritation in people, particularly those vulnerable to asthma (under Regulation (EU) No. 1169/2011 on the provision of food information to consumers). Hence, for prepacked foods, only $\leq$ 10 μg/g of SO_2 is deemed acceptable in the edible portion of the fruit and their presence in a food or beverage must be indicated on the label (expressed as SO_2), when the concentration surpasses 10 μg/g. This makes it vital for a shift from the use of sulphur treatments to alternative pre-treatment application for anti-browning management of litchi.

Increased postharvest losses coupled with high market demand for fresh fruit has driven the development of different storage technologies and handling protocols to preserve and prolong the overall quality during storage (Mangaraj et al., 2010). Modified atmosphere packaging, shrink wrap and vacuum packaging have been widely adopted to maintain fresh litchi fruit quality during prolonged storage (Sivakumar and Korsten, 2006a, b). However, due to sensitivity of litchi pericarp to browning and strict regulation on the use of sulphur, minimal processing of litchi fruit could serve as an alternative as well as convenient method for marketing (Shah and Nath, 2008; Dong et al., 2004). Minimally processed litchi has potential to be commercialized as a ready-to-eat product due to its sensorial quality and consumer convenience. The lack of blemishes such as decay, cracked fruit, pericarp browning, microbial infestation and aril firmness are the most important features for consumer acceptance.

Several studies have been reported on the minimal processing and pre-treatments of different varieties of litchi to preserve and prolong their shelf life (Bolaños et al., 2010; Dong et al., 2004; Shah and Nath, 2006, 2008; Kaushik et al., 2014; Phanumong et al., 2015, 2017; Phanumong et al., 2016). The application of dilute hypochlorite have been confirmed to be beneficial in prolonging the shelf life of fresh-cut tissues (Ayhan et al., 1998). However, the need for better understanding of the impact minimally processing on litchi fruit without the use of sulphur and other major anti-browning and firming agents pre-treatments remains crucial. Thus, the objective of this study was to investigate the effects of macro-perforated packaging on the quality attributes of minimally processed litchi cv. 'Mauritius' during cold storage and under retail conditions (shelf life), without the use of sulphur.

2. Materials and methods

2.1. Plant and packaging material

Litchi fruit cv. 'Mauritius' is an early ripening cultivar characterised by flesh, which is attached to the seed and makes it harder to separate from its seed. This cultivar represents 66% of the total production in South Africa. Fully matured litchi cv. 'Mauritius', were hand harvested from Fredenheim farm (25°25'58.9" S, 30° 59' 23.4" , E) in Nelspruit, South Africa in January 2018. Within 2 h after harvesting, the fruit were immediately transported under cool and well ventilated conditions to the Postharvest Laboratory at Agricultural Research Council (ARC) - Institute for Tropical and Subtropical fruit, Nelspruit. Fruit were immediately stored at 5 ± 0.5 °C, 95 % relative humidity (RH) for 5 days before processing. Clear polyethylene terephthalate (PET) clamshell trays (150 × 130 × 45 mm 350 mL) were obtained from Lowveld Packaging, Nelspruit, South Africa. Based on preliminary studies (data not shown) two perforation diameters/sizes 1.1 mm (P-1) and 5.4 mm (P-2) with 6 and 3 perforations on the lid, respectively were designed. Clamshell trays without perforations was used as control (P-0).

2.2. Sample processing and packaging

Fruit with cracks and splits were manually separated and fruit of uniform size were selected. Before processing and packaging, preparation area was sanitized with 70 % (v/v) ethanol (Ferreira et al., 2015). Selected whole fruit were randomized and treated with 200 ppm sodium hypochlorite (NaOCl, 3.5 % m/v) solution for 1 min. After draining, the fruit were carefully peeled without removing the pips. Arils obtained were then dipped into 50 ppm NaOCl solution using plastic strainer for 30 s and the solution was drained by placing the strainer on sterilized paper towel. Processing unit and distilled water used to prepare dipping solution were kept at ±16 °C for the duration of sample preparation. In a sterilized clamshell, approximately 9 pieces of arils (160 g to 180 g) were packed in each tray and immediately stored at 1 ± 0.5 °C and 90 ± 5 % RH. After processing the baseline measurements (day 0) were conducted prior to packaging and storage. During storage three clamshell per treatment were sampled on days 3, 6, 9, 12 and 15. In addition, on each sampling day additional three packages were taken and stored for 2 days at 12 ± 0.5 °C for shelf life study. Cold room temperature and relative humidity were monitored during the experiment at one-hour interval using data loggers (Pro-V2, Micro DAQ.com Ltd, USA).

2.3. Mass loss, juice leakage and decay incidences

Mass loss of each package were taken before storage and at each sampling day using digital analytical balance (SBA 16, Scaltec instruments, Germany). Mass loss of litchi fruit was taken after removing and quantifying juice leakage from the clamshell. The mass loss data were expressed in percentage (%) of the initial mass and calculated according to the Eq. (1):

$$\mathrm{WL} = \left[\frac{W_0 - \mathrm{W}_f}{W_0}\right] X\ 100 \tag{1}$$

where WL is the mass loss (%), W_0 is the initial mass (g) and W_f is the final mass (g) at the time of sampling during storage.

Juice leakage from the arils were measured using graduated cylinder and the results were expressed as mL/100 g. Juice leakage was determined by weighing the amount juice accumulated within the package during storage. Fruit decay incidences within the package was expressed as percentage evaluated during storage using the following scoring systems: 0 = without decay; 1 = 1–25 %; 2 = 25–50 %; 3 = 50–75 %; 4 = 100 %. An index of fruit decay was determined by multiplying the scores of severity by the number of fruit affected and dividing by the total number of fruit within the package (Artés et al., 1998).

2.4. Textural profile

From each clamshell, six arils were profiled individually. Measurements were performed using a texture analyser (TA-XT2 plus, Stable Micro Systems, UK). A 75 mm flat and round cylindrical aluminium probe was used to measure the firmness of the arils, expressed as maximum compression force (N) at room temperature (25 ± 0.5 °C). A test speed of 1.0 mm/s and distance of 30.0 mm were used in the measurements. Firmness defined as the force necessary to reach a given deformation (30 %) was calculated from the texture profile analysis (TPA) curve.

2.5. Colour

Colour was taken twice at the equatorial zone of both side of the fruit using colorimeter (lovibond® LC 100, Japan) in CIELAB (L^*, a^*, b^*) coordinates where L* denotes the lightness, a^*: red (+)/green (-) and b^*: yellow (+)/blue (-). White background (Illuminants C: Y = 83.44, x = 0.3051, y = 0.3202) was used for calibration before measurements were taken. The hue angle (h^o), ΔE and WI was calculated using Eqs. (2), (3), and (4), respectively, according to Pathare et al. (2013):

$$h^o = tan^{-1}\left(\frac{b^*}{a^*}\right) \tag{2}$$

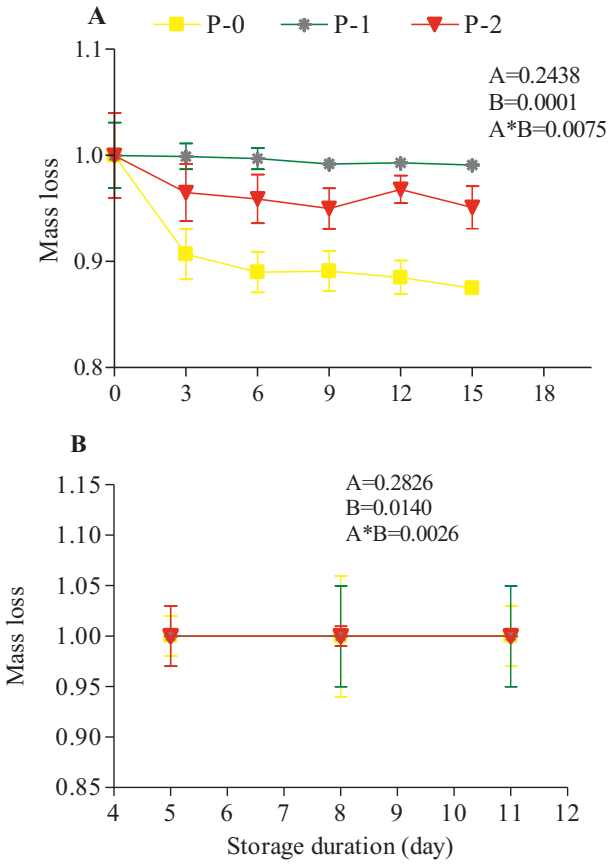

Figure 1. Changes in normalized mass loss of minimally processed litchi fruit cv. 'Mauritius' (A) during storage at 1 °C for 15 days, and (B) during shelf life (after each sampling day at 1 °C, additional packages were stored for 2 days at 12 °C). **Shelf life study samples taken from 1 °C storage was limited to day 9 due to decay. Bars represent the standard error of mean ($n = 3$). A = storage duration; B = packaging; and A*B = interaction effects at $p \leq 0.05$.

$$\Delta E = \sqrt{\Delta a^{*2} + \Delta b^{*2} + \Delta L^{*2}} \quad (3)$$

$$\mathrm{WI} = 100 - \sqrt{(100 - L)^2 + a^2 + b^2} \quad (4)$$

2.6. Chemical attributes

2.6.1. Total soluble solids (TSS), pH and titratable acidity (TA)

Litchi fruit juice total soluble solid in (°Brix) was measured using a digital refractometer (Atago, Tokyo, Japan) calibrated with distilled water at 20 °C. The pH was carried at room temperature with a pH metre (Mettler Toledo, South Africa). Maturity index was calculated as ratio between TSS and TA. Titratable acidity (TA) was determined by titrating 10 mL of the extracted juice mixed with 3 drops of phenolphthalein indicator against 0.1 N NaOH until the end-point at pH 8.2. The results were converted to citric acid and expressed as percentage (%). All measurements were done in triplicate.

2.6.2. Ascorbic acid

Ascorbic acid concentration was measured according to Klein and Perry (1982). Crude litchi juice (1 mL) was mixed with 10 mL of 1 % metaphosphoric acid and then sonicated in an ice bath for 4 min. The samples were then centrifuged at 4000 × g for 5 min. Supernatants (≈ 1.0 mL) were pipetted into a tube and mixed with 9 mL of 2,6 dichlorophenolindophenol dye (0.0025 %). The mixture was incubated in the dark for 10 min and the absorbance was measured at 515 nm using spetrophotometer (Jenway, UK). Standard curve of authentic $_L$-ascorbic acid ($y = -0.0045x + 0.5904$, $r^2 = 0.9722$) was used to calculate ascorbic acid content. Results were expressed as mass of ascorbic acid equivalents per volume of crude litchi juice, μg/mL.

2.7. Radical scavenging activity (RSA)

The ability of litchi juice to scavenge 2,2-diphenyl-1-picryl hydrazyl (DPPH) radical was determined using the method described by Karioti et al. (2004). Crude litchi juice (15 μL) was mixed with 735 μL methanol in centrifuge tubes followed by 0.1 mM solution of DPPH (750 μL) dissolved in the methanol solution. The mixture was incubated in the dark for 30 min at room temperature. The absorbance was measured at 517 nm using a UV-visible spectrophotometer (Jenway, UK). An ascorbic acid standard curve ($y = -0.158x + 0.7347$, $r^2 = 0.98$) was used to determine radical scavenging activity (RSA) and results were expressed as micromole ascorbic acid equivalent per millilitre of litchi juice (mmol AAE/mL).

2.8. Statistical analysis

The data obtained from the various measurements were subjected to two-way ANOVA using Statistix software versions (10, Tallahassee, FL). Means were separated by least significant difference (LSD; $P \leq 0.05$) according to Duncan's multiple range test. GraphPad Prism software version 4.03 (GraphPad Software, Inc., San Diego, USA) was used for graphical presentations. All results presented as mean ($n = 3$) values with standard error (± SE).

3. Results and discussion

3.1. Mass loss

It should be noted that mass loss of litchi fruit was taken after removing and quantifying juice leakage from the clamshell. Based on normalised mass loss result obtained, packaging design played a significant role in the mass loss (Figure 1). There was a significant interaction effect of storage duration and packaging on the mass loss of litchi fruit ($P = 0.0075$). Fruit packed in P-0 had higher mass loss than those under P-1 and P-2 at day 3 and remained relatively stable until the end of day 15. Minimally processed fruit packed in P-1 and P-2 showed negligible mass loss until the end of storage. Similar results were reported by Phanumong et al. (2015) in minimally processed litchi cvs. 'Honghuay', 'Gimseng' and 'Jugkapat' treated with peroxyacetic acid solution, packaged in polystyrene clamshell and stored at 4 °C for 12 days. Hussein et al. (2015) observed higher mass loss for minimally processed pomegranate arils in perforated packages. High water vapour permeability is enhanced by package perforations, which accelerates water uptake from packaged produce by evaporation resulting in increased mass loss (Hussein et al., 2015). At shelf life, storage duration and package interaction had a significant effect on mass loss ($P = 0.0026$). No significant changes in mass loss for minimally processed fruit across all package types was observed until the end of shelf life.

3.2. Textural profile

The results obtained showed that interaction effect of storage duration and packaging design had no significant impact on the fruit textural profile ($P = 0.0880$). While packaging design ($P = 0.001$) and storage duration ($P = 0.001$) independently had significant influence on fruit firmness (Figure 2). It was observed that fruit stored under P-2 (5.4 mm) perforated clamshell were firmer compared to those stored under P-1 (1.1 mm) and non-perforated from day 3 until day 12. Samples packed under non-perforated clamshell had the least firmness during the same

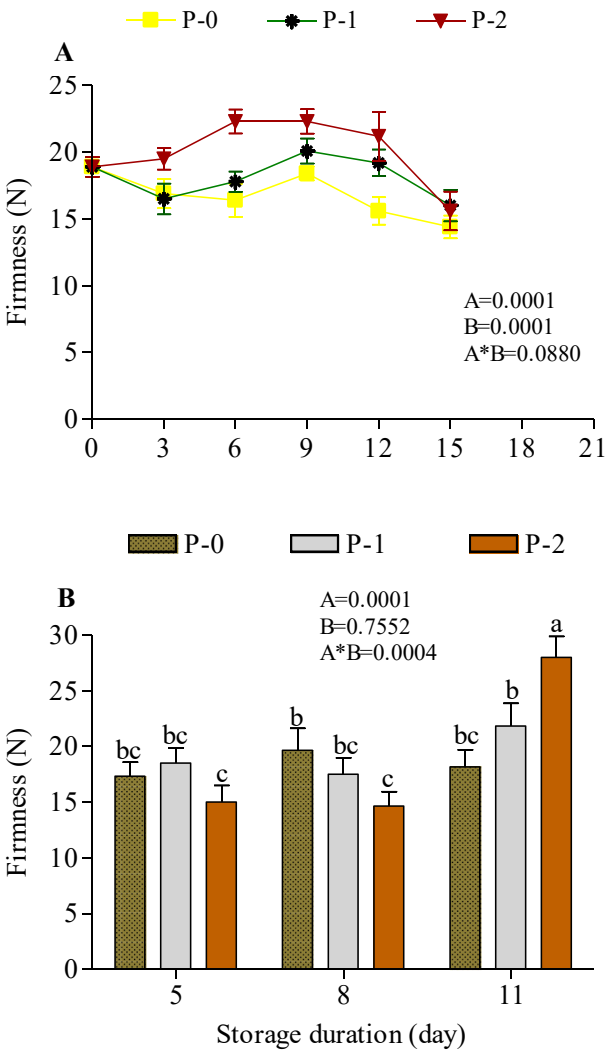

Figure 2. Changes in firmness (N) of minimally processed litchi fruit cv. 'Mauritius' (A) during storage at 1 °C for 15 days, and (B) during shelf life (after each sampling day at 1 °C, additional packages were stored for 2 days at 12 °C). **Shelf life study samples taken from 1 °C storage was limited to day 9 due to decay. Bars represent the standard error of mean ($n = 3$). A = storage duration; B = packaging; and A*B = interaction effects at $p \leq 0.05$.

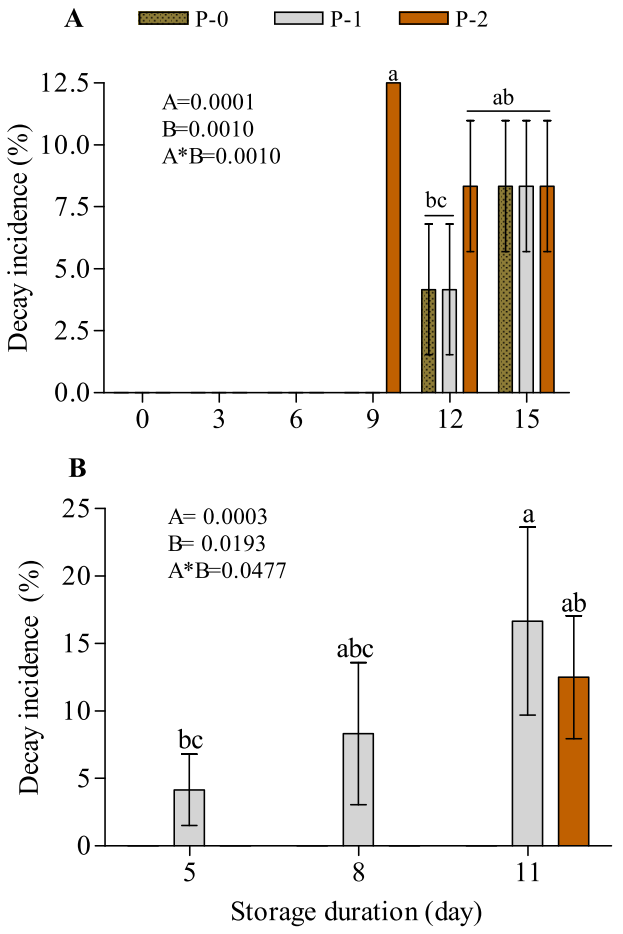

Figure 3. Decay incidences of minimally processed litchi fruit cv. 'Mauritius' (A) stored at 1 °C for 15 days, and (B) during shelf life (after each sampling day at 1 °C, additional packages were stored for 2 days at 12 °C). **Shelf life study samples taken from 1 °C storage was limited to day 9 due to decay. Bars represent the standard error of mean. A = storage duration; B = packaging; and A*B = interaction effects at $p \leq 0.05$.

period. At the end of day 15, a significant decline was observed across all package type with firmness ranging between 14.4 N and 16.0 N, but no significant difference was observed. Consistent with this study, Phanumong et al. (2015) observed a decline in firmness for non-treated minimally processed (deseeded) fruit cvs. 'Hongyuay', 'Gimseng' and 'Jugkapat' packed in polystyrene clamshell and stored at 4 ± 1 °C for 12 days. Similarly, Phanumong et al. (2017) observed a decline in firmness by 40 % in control fruit, while those under 2.5 % O_2 in combination with the CO_2 (5.0, 7.5 and 10.0 %) showed a decline by 39, 33 and 32 %, respectively, for deseeded litchi fruit cv. 'Jugkapat' stored for 18 days at 2 ± 1 °C.

The initial decline in firmness could be due to the onset of increased juice leakage as well as lack of firming agents, which could have resulted in membrane softening/solubilization. Softening of membrane is ascribed to activity of pectolytic enzymes such as methylesterase and polygalacturonase (Tanada-Palmu and Grosso, 2005). A notable variation in fruit firmness was observed as storage duration progressed. Fruit stored under P-2 were least firm at day 5 and 8 compared to those in P-1 and P-0 (non-perorated clamshell). However, an increase in firmness value was higher for fruit stored under P-2 (5.4 mm clamshell), while those stored under P-1 (1.1 mm) and P-0 did not change at day 11. Increased firmness could be due to hardening of the membrane as a result of evaporation from fruit surface.

3.3. Decay incidences

Decay incidences of minimally processed litchi fruit under different perforated packages at 1 °C are presented in Figure 3a. Storage duration, packaging as well as their interaction had an effect on the decay incidences of minimally processed fruit (P = 0.0010). As observed, the longer the fruit were kept in storage the higher the decay incidence prevailed. Between day 3 and 6, no signs of decay were observed across the package types. The decay incidences only started showing at day 9 in fruit packed under P-2 (5.4 mm) clamshell averaging 12.5 %, while no incidences were observed in fruit packed under P-0 and P-1 clamshell. However, at day 12, fruit packed under non-perforated and P-1 clamshell had decay incidence of 4.2 % while fruit in 5.4 mm remained unchanged (12.5 %). A two-fold increase in decay incidence (8.3 %) was observed at the end of storage for P-0 and P-1 packed fruit. The shelf life study showed that those packed in P-1 clamshell showed signs of mould at day 5 when stored at 12 °C and increased significantly between day 8 and 11 (Figure 3b). For non-perforated clamshell, no signs of decay where observed until day 11 while fruit packed under 5.4 mm package had a decay incidence of 12.5 %.

Furthermore, a slight but insignificant decline in fruit decay incidence was observed in fruit packed in P-2 clamshell at the end of storage. The

Table 1. Changes in the physical attributes of minimally processed litchi cv. 'Mauritius' during storage at 1 °C, and after shelf life at 12 °C.

Day	Packaging	Juice leakage	WI	Colour change (ΔE)	P-value			
						JL	WI	(ΔE)
0	P-0	0.00 ± 0.00c	52.14 ± 2.26cde	0.0 ± 0.00c	Storage duration (A)	**0.0175**	0.0773	**0.0001**
	P-1	0.00 ± 0.00c	52.14 ± 2.26cde	0.0 ± 0.00c	Packaging (B)	**0.0001**	0.1407	0.4742
	P-2	0.00 ± 0.00c	52.14 ± 2.26cde	0.0 ± 0.00c	A*B	**0.0001**	0.1273	0.4325
3	P-0	12.18 ± 0.53b	59.83 ± 6.36a	15.89 ± 6.58a				
	P-1	-1.65 ± 0.90c	49.69 ± 0.87e	8.01 ± 1.00b				
	P-2	-0.33 ± 1.37c	50.27 ± 1.02de	8.20 ± 1.02b				
6	P-0	19.04 ± 4.69a	54.00 ± 1.10b-e	8.18 ± 1.35b				
	P-1	-1.75 ± 0.94c	54.02 ± 1.42b-e	7.68 ± 2.11b				
	P-2	-0.19 ± 1.66c	55.00 ± 1.26a-e	6.65 ± 1.42b				
9	P-0	9.64 ± 2.49 b	55.51 ± 0.87a-d	7.35 ± 1.76b				
	P-1	-1.69 ± 0.95c	57.85 ± 0.99abc	9.77 ± 1.68b				
	P-2	0.25 ± 1.67c	54.56 ± 0.99a-e	6.86 ± 1.49b				
12	P-0	11.62 ± 3.01b	54.18 ± 1.08a-e	6.47 ± 1.71b				
	P-1	-1.75 ± 0.95c	55.51 ± 1.49a-d	6.77 ± 1.21b				
	P-2	-1.09 ± 1.56c	54.11 ± 1.39a-e	9.00 ± 1.91b				
15	P-0	11.97 ± 3.05c	59.48 ± 1.68ab	9.77 ± 2.49b				
	P-1	-1.62 ± 0.95c	55.50 ± 0.87a-d	6.68 ± 1.72b				
	P-2	-0.09 ± 1.52c	55.36 ± 1.21a-e	8.98 ± 2.29b				
***Shelf life (12 °C)**					**P-value**	**JL**	**WI**	**(ΔE)**
5	P-0	6.97 ± 0.53cd	52.43 ± 0.94c	12.64 ± 5.15a	Storage duration (A)	**0.0001**	0.1661	0.0890
	P-1	5.54 ± 0.08d	56.07 ± 0.98ab	7.03 ± 1.05b	Packaging (B)	0.4049	0.5212	0.4683
	P-2	5.49 ± 0.73d	54.88 ± 1.00abc	6.11 ± 0.79b	A*B	0.2802	**0.0415**	0.2517
8	P-0	8.99 ± 1.45bc	57.07 ± 1.35ab	5.42 ± 0.93b				
	P-1	12.13 ± 2.24a	54.97 ± 0.80abc	5.20 ± 0.75b				
	P-2	10.03 ± 1.05ab	55.69 ± 1.29abc	4.92 ± 0.44b				
11	P-0	9.52 ± 0.25abc	58.37 ± 1.25a	4.83 ± 0.95b				
	P-1	10.52 ± 0.63ab	56.46 ± 1.87ab	6.94 ± 1.82b				
	P-2	10.03 ± 0.43ab	54.11 ± 1.39bc	5.94 ± 0.97b				

Mean ($n = 3$) ± standard error in the columns with different lower case letters are significantly different ($p \leq 0.05$) along the storage duration. *Shelf life represents the average retail condition. Shelf life (after each sampling day at 1 °C, additional packages were stored for 2 days at 12 °C). Shelf life study samples taken from 1 °C storage was limited to day 9 due to decay. JL = juice leakage; WI = whiteness index; ΔE = total colour change.

physical injury due to fruit processing dislocates surface tissues, expose cytoplasm which in turn provide a potentially richer source of nutrients for spoilage microorganisms than intact produce (Brackett, 1994). Similar to our findings, Somboonkaew and Terry (2010) detected no disease in non-acid and SO_2 free litchi fruit packaged in modified atmosphere packaging stored at 13 °C for 9 days. Pesis et al. (2002) found that litchi packed in micro-perforated modified atmosphere packaging stored for 4 weeks at 1.5 ± 0.5 °C, 90 % RH had less decay incidences.

3.4. Juice leakage

Juice leakage is major factor limiting the longevity and quality of fresh-cut fruit including watermelon (Mao et al., 2005), papaya (Ergun et al., 2006) and cantaloupe (Luna-Guzman et al., 1999). Table 1 present juice leakage of minimally processed litchi fruit stored under different packaging types. In the present study, juice leakage was significantly affected by both storage duration and packaging type as well as their interaction (P = 0.0001). Juice leakage increase in minimally processed litchi fruit with prolonged storage could be attributed to the removal of protective pericarp exposing fruit to multiple extrinsic factors (Dong et al., 2004). As observed, juice leakage was significantly higher in P-0 (12.18 mL/100 g) compared to P-1 (1.65 mL/100 g) and P-2 clamshell (0.33 mL/100 g) at day 3. After day 6, a significant increase from 12.18 to 19.04 mL/100 g was found in fruit packed under non-perforated clamshell, while those under P-1 and P-2 were 1.75 mL/100 g and 0.19 mL/100 g, respectively.

Similar results in increase in juice leakage with prolonged storage of minimally processed litchi cultivars was reported by other authors (Shah and Nath, 2006; 2008; Kaushik et al., 2014; Phanumong et al., 2015). Shah and Nath (2008) suggested that juice leakage resulted from loss of cellular sap due to biochemical changes. In the present study, it could be suggested that increased juice leakage might have been further aggravated by the maturity stage since the fruit were not deseeded. Factors associated with deteriorative changes by enzymatic activities and microbial infestation weakening resulted in juice leakage (Aklimuzzaman et al., 2011; Khan et al., 2012). Toivonen and Brummell (2008) suggested that drip losses may further be aggravated by mechanical damage or as a result of biochemical alterations at the cell wall, middle lamella and membrane levels.

During shelf life study, there was a consistent increase in juice leakage across all package types. On day 5 juice leakage from the arils was 5.49, 5.54 and 6.97 mL/100 g for fruit packed in P-2, P-1 and P-0, respectively (Table 1). A notable increase was observed at day 8 with higher juice leakage observed in perforated clamshells and remained unchanged on day 11 across all packages. Increased juice leakage could probably be due to higher storage temperature (12 °C) in the present study in combination with fruit senescence.

3.5. Whiteness index (WI) and colour change (ΔE)

Generally, whiteness indices correlate closely with consumers' preferences for white colours (Pathare et al., 2013). Whiteness index of the minimally processed litchi fruit was not significantly (P = 0.1273)

affected by storage duration and packaging as well as their interaction effects (Table 1). This observation is consistent with report presented by Phanumong et al. (2015) in minimally processed litchi fruit cv. 'Hongyong', 'Gimjeng' and 'Jugkapat' packed in polystyrene clamshell stored at 4 ± 1 °C for 12 days. On the other hand, during shelf life study at 12 °C whiteness index of the minimally processed fruit was higher in fruit packed under perforated clamshells (P-1 and P-2) compared to those from non-perforated clamshell (P-0) at day 5. A slight increase in whiteness index was detected in fruit packed in P-0 which did not vary significantly with the fruit from the perforated clamshells after 8 days shelf life. The whiteness index remained relatively unchanged at day 11 across all package type. Minimally processed fruit colour change was not significantly affected by both storage duration and package type (P = 0.2517) (Table 1). However, fruit from non-perforated clamshell had notably higher colour change at day 5 compared to perforated clamshells. There was a decline by half (from 12.64 to 5.42) in colour change for fruit packaged under non-perforated clamshell whereas those in perforated clamshell remained unchanged but was statistically insignificant. Kaushik et al. (2014) suggested that a decrease in colour change could be due to development of pink discolouration found in litchi fruit. According to Chandler and Clegg (1970) pink discolouration might be due to the hydrolysis of condensed tannin to catechin and lencoanthocyanin concentration which was found to be more prevalent in canned pear fruit.

In contrast to WI, colour change significantly increased with storage duration (P = 0.0001), but packaging and storage duration interaction effect had no significant on colour change (Table 1). According to Patras et al. (2011) total colour difference (colour change) specifies the degree of colour difference between stored and control samples. Fruit packed under P-0 clamshell had greater colour change averaging 15.89 than P-2 (8.20) and P-1 (8.01) at day 3. However, colour change decreased by half (from 15.89 to 8.18) in fruit packed under non-perforated clamshell while fruit under P-1 and P-2 clamshell did not change after day 6. No significant change was observed from day 9 until the end of storage duration across all package types. However, brown patches were visually observed at the distal end of the fruit where colour measurement could not be taken.

3.6. Chemical properties

3.6.1. Total soluble solids

Biochemical attributes of minimally processed litchi fruit are presented in Figure 4. The TSS content of the minimally processed litchi was influence by storage and packaging as well as their interaction (P = 0.001) (Figure 4a). TSS content was 17.73 % at day 0 and increased gradually with storage duration. An increment by 2 (18.11 °Brix) to 3 % (18.38 °Brix) was observed in fruit packed under P-0 and P-2 clamshells, respectively after 3 day of storage and remained relatively stable until day 9. Furthermore, those packed under P-1 (17.70 °Brix) clamshells had lower TSS with no significant change until the end of storage. A significant increase in TSS for those packed under P-0 (19.56 °Brix) and P-2 (19.38 °Brix) clamshell was observed and all packages maintained similar amount at the end of storage. It is suspected that an increase in TSS might be due to ripening changes (Aklimuzzaman et al., 2011). TSS content recorded at the end of storage were in the range reported by Phanumong et al. (2015) in non-treated minimally processed litchi cv. 'Gimseng' stored at 4 ± 1 °C for 12 days. TSS values at the end of storage were similar to those observed in minimally processed litchi cv. 'Racimo Rojo' disinfected with 50 ppm NaOCl stored at 2, 5 and 10 °C (Bolaños et al., 2010). Shelf life study was conducted only on day 5 and 8 due to decay incidences observed at day 11 (Table 2). Storage duration and packaging type as well as their interaction did not affect TSS content of minimally processed fruit (P = 0.3234). TSS was between the range of 18.96 and 19.15, and remained relatively stable on day 8.

3.6.2. Titratable acidity

Titratable acidity was significantly influenced by storage duration (P = 0.0001) (Figure 4b). At day 0, TA level was 1.13 % across all package type and decreased gradually with storage duration irrespective of package type. A significant decline in TA by approximately 82 % was

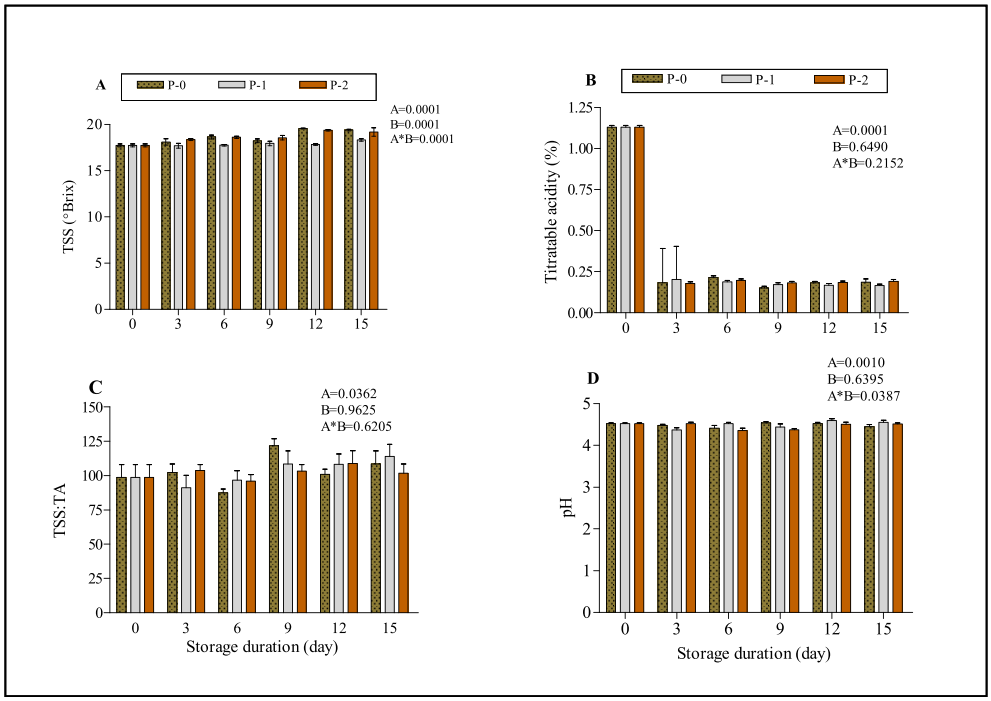

Figure 4. Biochemical attributes (A) total soluble solids (TSS); (B) titratable acidity (TA); (C) TSS:TA ratio; and (D) pH, of minimally processed litchi fruit cv. 'Mauritius' during storage at 1 °C for 15 days. Bars represent the standard error of mean ($n = 3$). A = storage duration; B = packaging; and A*B = interaction effects at $p \leq 0.05$.

observed in all package type after 3 days of storage. No significant change in TA level was observed for fruit packed under P-2 perforated punnets from day 6 until the end of storage. Fruit packed in non-perforated punnets had notably higher TA level than fruit from perforated punnets after 6 days of storage whereas no significant change was observed for fruit under P-2 clamshell trays. A slight decline was detected at day 9 across all package type which increased at day 12 while fruit packed under P-1 remained unchanged. At the end of storage, the TA level was 0.16, 0.18 and 0.19 % for fruit packed in P-1, P-0 and P-2, respectively. However, the TA level did not vary significantly. Our results are inconsistent with those reported in minimally-processed litchi cv. 'Rose' packed under plastic trays sealed with polypropylene film subjected to moderate vacuum condition during storage at 4 ± 1 °C which showed increasing trend (Shah and Nath, 2008). Similar to our results, Dong et al. (2004) reported a significant decline in TA in peeled litchi cv. 'Huaizhi' treated with chitosan stored for 6 days at -1 °C. During shelf life on day 5, fruit packed under P-0 clamshells (0.22 %) maintained higher TA level (Table 2), followed P-1 (0.17 %) and P-2 (0.16 %). However, there was no significant difference between the packages and remained unchanged until day 8 shelf life. The TA level decreased on day 8 for fruit packed under1.1 mm to the same level as P-0 and P-2 samples.

3.6.3. TSS:TA

There was no significant interaction effect of storage duration and packaging on the TSS:TA ratio of minimally processed fruit (P = 0.6205) (Figure 4c). The result show however that TSS:TA ratio was significantly affected by storage duration. It is widely reported that TSS:TA ratio of litchi pulp/aril is highly correlated to eating quality. TSS:TA ratio of 98.86 was observed at day 0 and gradually increased by approximately 1-fold for fruit packed in P-0 and P-2 compared to P-1 clamshell after 3 days of storage. The TSS:TA ratio did not change at day 6, however, a lower amount was observed in P-0 clamshell. After day 9, significantly higher TSS:TA ratio was observed in P-0 averaging 121.63 compared to fruit packed under P-1 (108.44) and P-2 (103. 35) clamshell but did not vary significantly. A decline by 15 % (from 121.63 to 102.20) was observed in non-perforated whereas the perforated clamshell (108.25 for P-1; 108.77 for P-2) remained unchanged after 12 days of storage. Fruit under P-1 (114.1) best maintained TSS:TA ratio than the fruit packed under P-0 (108.45) and P-2 (101.83) clamshell at the end of storage but were statistically insignificant. The optimum TSS:TA ratio of litchi is in the range of 30-40 where TSS:TA ratio of greater than 80:1 is regarded as over-mature (Schoeman et al., 2005). Our results show that the fruit were harvested entirely at an advanced stage than recommended maturity for litchis and all the package type did not maintain the ratio at the end of the storage. The TSS:TA reported in this study is higher than those reported in other litchi cultivars. For instance, Phanumong et al. (2015) recorded TSS:TA in the range of 30-40, 50–60 and 40–60 in litchi cvs. 'Honghuay', 'Gimseng' and 'Jugkapat', respectively.

On day 5 of shelf life, fruit packed under non-perforated clamshells had the lowest TSS:TA ratio (84.47) (Table 2). Moreover, those under P-2 had the highest TSS:TA ratio averaging 124.47 but did not vary significantly with those packed in P-1 (110.66) clamshells. A notable decline was observed on day 8 of shelf life for those under P-2 (103.87) and P-1 (90.99) clamshell while an increase was observed in P-0 (110.11).

3.6.4. pH

There was significant interaction effect of storage duration and packaging on pH (P = 0.0387) (Figure 4d). At day 0, pH value was 4.51 across all package and showed gradual fluctuation with prolonged storage. Fruit packed under P-1 (4.36) perforation had the lowest pH value followed by those under P-0 (4.47) while no significant change was observed for fruit under P-2 (4.51) clamshell after 3 days of storage. However, those under P-0 and P-2 did not vary significantly during the same period. No obvious changes in pH level was observed after 6 days of storage across all package type. However, an increase in pH level by 1-fold was observed at day 9 for those under P-0 (from 4.41 to 4.53) while fruit under P-1 and P-2 did not change. A different trend was observed at day 12 where fruit packaged in P-1 had slightly higher pH level averaging 4.58 than P-0 (4.51) and P-2 (4.50) clamshell. At the end of storage, notable but insignificant variation in pH level was observed across all package type which did not differ from that of day 0. For instance, pH level was 4.55, 4.51 and 4.44 for fruit under P-1, P-2 and P-0, respectively.

The pH values were found to be within those reported in untreated minimally processed litchi 'Bombai' variety stored at 5 °C for 12 days (Aklimuzzaman et al., 2011; Kaushik et al., 2014). Shah and Nath (2006) observed a significant decline in pH in control fruit from initial value of 4.65-4.75 to 3.65-4.3 at 20 days. Moreover, Shah and Nath (2008) reported a decline in minimally processed litchi cv. 'Rose' scented stored at 4 ± 2 °C for 12 days. The interaction of storage duration and packaging had a significant influence on pH level during shelf life (P < 0.0005) (Table 2). On day 5, P-2 packed fruit had higher pH level with an average of 4.71 followed by P-1 (4.62) but did not vary significantly while the lowest was detected in P-0 (4.44) packed fruit. A notable decrease was observed in fruit packed under P-1 and P-2, while those under P-0 remained stable at day 8 of shelf life.

3.6.5. Ascorbic acid

The interaction effect of storage duration and packaging type significantly affected vitamin C of minimally processed fruit (P < 0.0001) (Figure 5a). The initial value at day 0 was 63.42 μg/mL and increased by approximately 10 % for fruit packed under perforated clamshell on day 3

Table 2. Changes in the chemical attributes of minimally processed litchi cv. 'Mauritius' during shelf life at 12 °C.

Storage duration	Packaging	TSS (°Brix)	TA (% citric)	TSS:TA	pH
5	P-0	19.15 ± 0.16ab	0.22 ± 0.02a	84.47 ± 3.26d	4.44 ± 0.29abcd
	P-1	18.96 ± 0.16ab	0.17 ± 0.01bc	110.66 ± 7.19ab	4.62 ± 0.06ab
	P-2	18.96 ± 0.17ab	0.16 ± 0.01c	124.47 ± 9.71a	4.71 ± 0.02a
8	P-0	19.53 ± 0.04a	0.18 ± 0.01bc	110.11 ± 3.42ab	4.50 ± 0.02c
	P-1	17.48 ± 0.64b	0.19 ± 0.01b	90.99 ± 7.54cd	4.34 ± 0.02d
	P-2	18.38 ± 0.26ab	0.18 ± 0.01bc	103.87 ± 4.12bc	4.71 ± 0.04ab
P-value					
Storage duration (A)		0.2151	**0.0018**	**0.0306**	**0.0022**
Packaging (B)		**0.2060**	0.5931	0.3550	**0.0003**
A*B		**0.3234**	**0.0005**	**0.0011**	**0.0005**

Mean ($n = 3$) ± standard error in the columns with different lower case letters are significantly different ($p \leq 0.05$) along the storage duration. *Shelf life represents the average retail condition. Shelf life (after each sampling day at 1 °C, additional packages were stored for 2 days at 12 °C). Shelf life study samples taken from 1 °C storage was limited to day 9 due to decay. JL = juice leakage; WI = whiteness index; ΔE = total colour change. Data for all the packages for day 11 was discontinued due to high incidence of decay.

while those under control (P-0) experienced significant decline by 26 %. General decrease in vitamin C concentration was observed at day 6 with fruit packed under P-2 having notably higher amount followed by P-1 and P-0 (non-perforated clamshell). However, an increase was observed after day 9 with higher amount in fruit under non-perforated clamshell compared to P-1 while fruit packed in P-2 had the lowest. A drastic decline was observed at day 12 with no variation observed at day 15 across all package type.

Similarly, a decreasing trend was observed across all package type during shelf life with the lowest vitamin C concentration at on day 11. The Ascorbic acid concentration was 36.16, 33.23 and 32.79 μg/mL for fruit packed under P-2, P-1, and P-0 clamshell. Our results showed that none of the packages prevented loss of ascorbic acid. Similarly, Kaushik et al. (2014) reported significant decline in ascorbic acid (vitamin C) in minimally processed litchi 'Bombai' stored at 5 °C for 12 days. Shah and Nath (2008) also observed a decrease in ascorbic acid in minimally processed litchi cv. 'Rose' scented treated with anti-browning agent and vacuum packaged during storage at 4 ± 2 °C for 24 days. Oxidative degradation during storage could also lead to its rapid reduction of ascorbic acid contents (Piga et al., 2003).

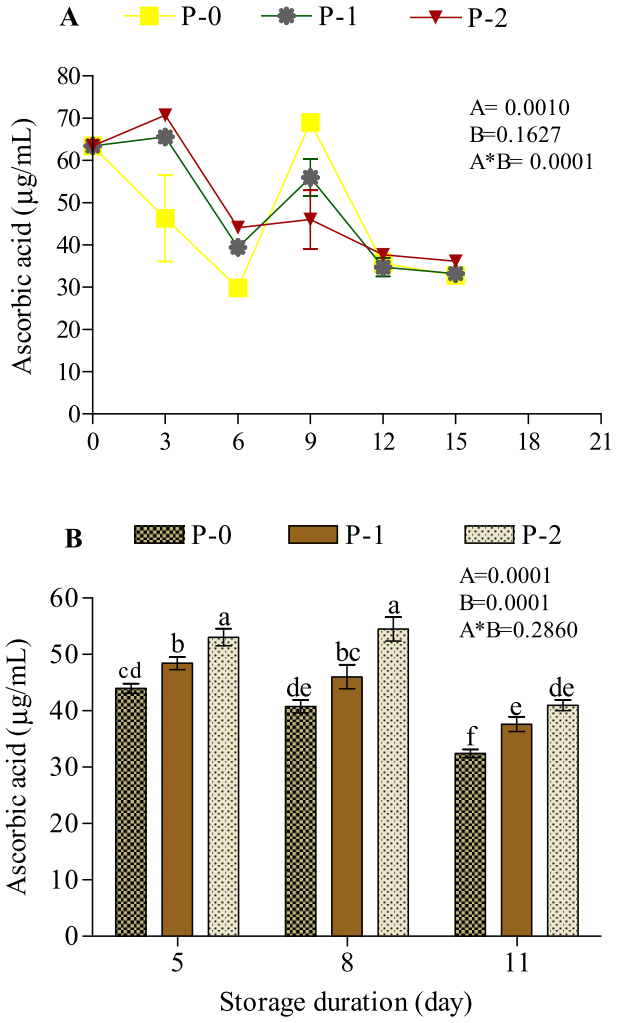

Figure 5. Ascorbic acid of minimally processed litchi fruit cv. 'Mauritius' (A) during storage at 1 °C for 15 days and (B) during shelf life (after each sampling day at 1 °C, additional packages were stored for 2 days at 12 °C). **Shelf life study samples taken from 1 °C storage was limited to day 9 due to decay. Bars represent the standard error of mean ($n = 3$). A = storage duration; B = packaging; and A*B = interaction effects at $p \leq 0.05$.

3.7. Radical scavenging activity

The radical scavenging activity in pulp tissues of litchi fruit progressively and continuously decreased with prolonged storage duration across all treatments. The radical scavenging activity of minimally processed litchi was significantly affected by the interaction of storage duration and packaging (P = 0.0048) (Figure 6a). The concentration declined by almost 80 % at day 8 for those packed in perforated clamshell, while non-perforated packed fruit decreased by 91 % from the initial value of 143.90 mmol AAE/mL. None of the package preserved the radical scavenging activity. At the end of the storage, radical scavenging activity decreased further to the value of 10.63, 8.17 and 7.47 mmol AAE/mL for P-1, P-0, and P-2, respectively. Under the shelf life study, packaging significantly affected the radical scavenging activity of minimally processed fruit (P = 0.0001) (Figure 6b).

Similar observation of continuous decline in DPPH radical scavenging activity was reported by Duan et al. (2011) and Ali et al. (2016) during storage of litchi fruit. In the present study, decrease of radical scavenging

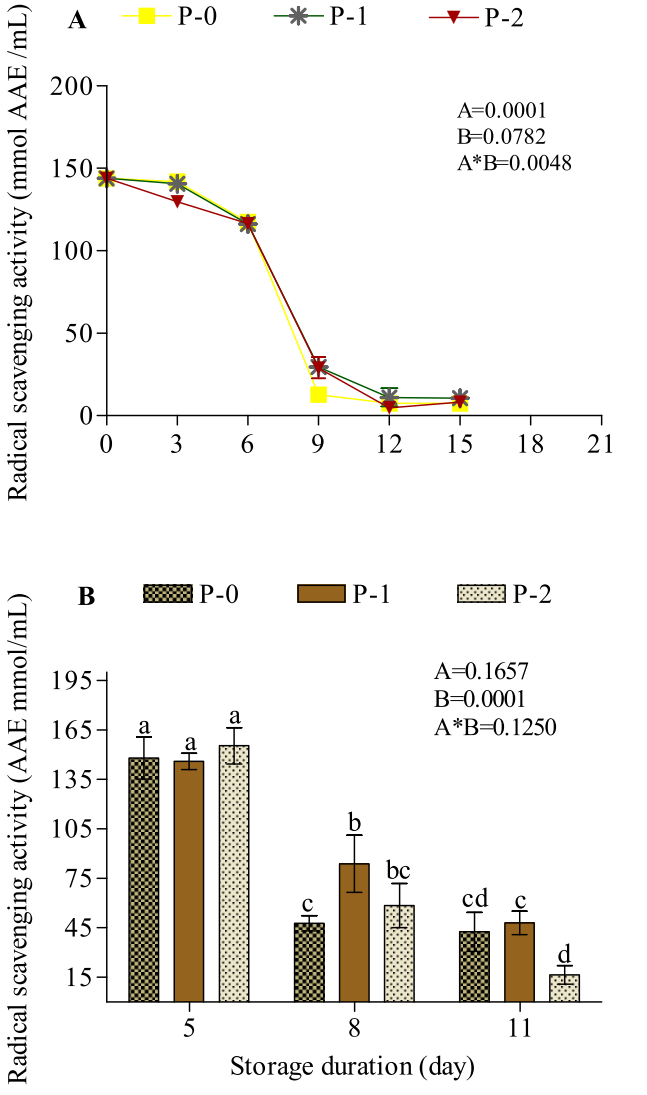

Figure 6. Changes in radical scavenging activity of minimally processed litchi fruit cv. 'Mauritius' (A) during storage at 1 °C for 15 days and (B) during shelf life (after each sampling day at 1 °C, additional packages were stored for 2 days at 12 °C). **Shelf life study samples taken from 1 °C storage was limited to day 9 due to decay. Bars represent the standard error of mean. Bars represent the standard error of mean ($n = 3$). A = storage duration; B = packaging; and A*B = interaction effects at $p \leq 0.05$.

activity during storage could be associated with decreased concentration of ascorbic acid, as similar pattern was observed. This implies that higher retention in the amount of ascorbic acid would maintain a higher radical scavenging activity. Consistent with the observations from this study, Du et al., 2009 found a linear relationship between ascorbic acid content and the radical scavenging activity. Similarly, higher radical scavenging activity due to higher retention of bioactive compounds such as ascorbic acid, phenolics, flavonoids etc. has also been reported earlier in litchi (Duan et al., 2007).

4. Conclusion

The study demonstrated that minimally processed litchi fruit could be stored for up to 9 days using non-perorated and 1.1 mm clamshell without any signs of decay. However, none of the packages prevented loss of aril mass, TA, ascorbic acid and radical scavenging activity. TSS and TSS:TA were higher irrespective of the package type. Whiteness index of minimally processed litchi fruit were well preserved by the clamshells, however, total colour difference was significantly affected by the storage duration. The main limitations to storage of minimally processed litchi fruit was juice leakage and incidence of decay. These results indicated the potential for non-sulphur treated minimally processed litchi fruit packed in clamshell tray to maintain the postharvest freshness and reduce the economic loss.

Declarations

Author contribution statement

Rebogile R Mphahlele: Performed the experiments; Wrote the paper.

Oluwafemi James Caleb: Analyzed and interpreted the data; Wrote the paper.

Mduduzi E.K E.K. Ngcobo: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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