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

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ARTICLE INFO

Keywords:
Food science
Food packaging
Food quality
Agricultural science
Horticulture
Litchi
Allergen
Total soluble solids
Radical scavenging activity
Ascorbic acid
Decay

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 (SO2) 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 SO2 on the quality attributes of minimally processed litchi fruit cv. ‘Mauritius’. 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 ratio 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 (Raiser et al., 1994). In order to prolong the shelf life of litchi fruit, sulphur dioxide (SO2) 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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https://doi.org/10.1016/j.heliyon.2020.e03229
Received 22 August 2019; Received in revised form 17 December 2019; Accepted 10 January 2020
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reactions and other allergic reactions when ingested by sensitive individuals (Koeng 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 \( \leq 10 \mu g/g \) 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 \( \mu g/g \). 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 (Bolanos 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 (Ayyan 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 Mauritius. Fully matured litchi cv. ‘Mauritius’, were hand harvested from Fredenheim farm (25° 25’ 58.95’, 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 x 130 x 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 pits. 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, Scatec 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):

\[
WL = \frac{W_0 - W_f}{W_0} \times 100
\]

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 \((L^*, a^*, b^*)\) co-ordinates 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 \((h^*)\), \( \Delta E \) and WI was calculated using Eqs. (2), (3), and (4), respectively, according to Pathare et al. (2013):

\[
h^* = \tan^{-1} \left( \frac{b^*}{a^*} \right)
\]

\[
\Delta E = \sqrt{(L^* - L^*)^2 + (a^* - a^*)^2 + (b^* - b^*)^2}
\]

\[
WI = \frac{L^* + a^* + b^*}{3}
\]
The mixture was incubated in the dark for 10 min and the absorbance was measured at 515 nm using spectrophotometer (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, $\mu$g/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 $\mu$L) was mixed with 735 $\mu$L methanol in centrifuge tubes followed by 0.1 mM solution of DPPH (750 $\mu$L) 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 ($\pm$ 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. ‘Honghua’, ‘Gimseng’ and ‘Jugkapat’ treated with peroxycetic acid solution, packaged in polystyrene clamshell and stored at 4 $^\circ$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
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% O2 in combination with the CO2 (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 ofpectolytic enzymes such as methylesterase and polygalacturonase (Tamada-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-perforated 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.

**Shelf life study samples taken from 1 day. Similarly, Phanumong et al. (2017) observed a decline in ¼ B decay. Bars represent the standard error of mean (juice leakage as well as lack of each sampling day at 1/C6 and 2/C14, ½/C3/C14, and increased significance for 1/C14 and increased significance for 1/C14). **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 ≤ 0.05.

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 6 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
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 SO2 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 (1.75 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.

| Day | Packaging | Juice leakage (mL/100 g) | Whiteness index | Colour change (ΔE) | P-value | JL | WI | (ΔE) |
|-----|-----------|--------------------------|----------------|-------------------|---------|----|----|------|
| 0   | P-0       | 0.00 ± 0.00c              | 52.14 ± 2.26de | 0.00 ± 0.00c      | Storage duration (A) 0.0175 | 0.0773 | 0.0001 |
|     | P-1       | 0.00 ± 0.00c              | 52.14 ± 2.26de | 0.00 ± 0.00c      | Packaging (B) 0.0001 | 0.1407 | 0.4742 |
|     | P-2       | 0.00 ± 0.00c              | 52.14 ± 2.26de | 0.00 ± 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 ± 2.49b              | 55.51 ± 0.87a-d| 7.25 ± 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| 8.66 ± 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| 7.77 ± 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)

5

| Day | Packaging | Juice leakage (mL/100 g) | Whiteness index | Colour change (ΔE) | P-value | JL | WI | (ΔE) |
|-----|-----------|--------------------------|----------------|-------------------|---------|----|----|------|
| 8   | 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 ± 1.00ab | 6.61 ± 0.79b      | A*B 0.2802 | 0.0415 | 0.2517 |
| 11  | P-0       | 8.99 ± 1.45bc            | 57.07 ± 1.35ab | 5.42 ± 0.93b      |                      |       |    |      |
|     | P-1       | 12.13 ± 2.24a            | 54.97 ± 0.80ab | 5.20 ± 0.75b      |                      |       |    |      |
|     | P-2       | 10.03 ± 1.05ab           | 55.69 ± 1.29abc| 4.92 ± 0.44b      |                      |       |    |      |
| 15  | 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 < 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.

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; Phumumong 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)
Biochemical attributes of minimally processed litchi fruit are presented in Figure 4. The TSS content of the minimally processed litchi was influenced 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 (18.38 °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 (Bolanos 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 observed at the distal end of the fruit where colour measurement could not be taken.

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 ≤ 0.05.
observed in all package type after 3 days of storage. No significant change was observed in TA level was observed for fruit packed under perforated clamshell on day 3 (Aklimuzzaman et al., 2011; Kaushik et al., 2014). Shah and Nath (2006) reported a decline in minimally processed litchi cv. ‘Bombai’ variety stored at 5 °C for 12 days (Aklmizzaman 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 type 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.
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).

### 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 activity in pulp tissues of 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 ≤ 0.05.

![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 ≤ 0.05.](image)

![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 ≤ 0.05.](image)
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 no-perforated 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.

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

Funding statement

This work was supported by Agricultural Research Council under Professional and Graduates Development Programme.

Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

Acknowledgments

Karen De Jager is greatly thanked for assisting with fruit transportation, affording us access to processing unit and providing us with consumables to carry out sample preparations. The author like to express sincere gratitude to Innocent Ratlapan, Joyce Mathopo, Justice Mlimi, Sandile Dlamini and Senzo Lubisi for their assistance during sample preparation, processing and packaging of litchi fruit.

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