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Influence of temperature and packaging on physiological and chemical profiles of imported litchi fruit

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ABSTRACT

The aim of this study was to detail the physiological and biochemical changes in non-adulterated and commercially-treated litchi fruit stored in different packaging films under different storage temperatures. Litchi fruit cv. Mauritius treated with either SO₂ and acid (commercially-treated fruit), or free from both SO₂ and acid (non-adulterated fruit), were imported from Israel and packed using two different packaging films *viz.* micro-perforated polypropylene or PropaFresh™ PFAM, or stored unwrapped, at 5 or 13°C for 11 days. Both CO₂ and ethylene concentrations were lower in commercially-treated fruit and at storage of 5°C but higher in PropaFresh™ PFAM films. Weight loss was least in commercially-treated fruit wrapped with PropaFresh™ PFAM at 5°C. Non-adulterated fruit wrapped in PropaFresh™ PFAM had higher individual aril sugars and organic acids whilst commercially-treated fruit retained higher concentrations of anthocyanins. These results indicate that PropaFresh™ PFAM packaging at 5°C could be used to maintain postharvest quality in both commercially-treated and non-adulterated litchi fruit.

Keywords: acid treatment, anthocyanin, carbon dioxide, ethylene, MAP, organic acid, sugar

1. Introduction

Litchi fruit is usually distributed by air from the growers to the overseas customers in 15 days. Deterioration of the postharvest quality of litchi fruit during distribution could be caused by fruit maturity and senescence (Sharma, Ray & Rai, 1986; Huang & Wang, 1990), disease (Huang & Scott, 1985; Sivakumar, Arrebola & Korsten, 2008), ethylene exposure and heat and chilling injury (Wong, Jacobi & Giles, 1991; Tongdee, Scott & McGlasson, 1982; Mcquire, 1997). Pericarp discolouration is one of the principal reasons for customer complaints.

The mechanism of litchi pericarp browning has been mainly attributed to polyphenol oxidase (PPO) and high peroxidase (POD) activities (Zhang, Pang, Xuewu, Ji & Jiang, 2005), ascorbic acid oxidation (Jurd, 1972; Jiang, 2000) and degradation of anthocyanins (Huang, Hart, Lee & Wicker, 1990; Jiang & Fu, 1999). These factors are associated with the aforementioned stresses (e.g. heat injury) can lead to moisture loss and subsequent disruption of cellular compartmentalisation. Thus, PPO and anthocyanase located in the chloroplasts and other plastids can react with phenolic or anthocyanin substrates located in the vacuole, forming quinone or anthocyanidin which finally results in the production of melanin (brown pigments) in litchi pericarp (Underhill & Critchley, 1995; Jiang et al., 2006).

Sulphur dioxide (SO₂) not only controls postharvest disease but also can effectively preclude the incidence of browning in litchi pericarp by transforming to

colourless chromen-2 (or chromen-4) sulphonic acid (quinin-sulphite complex) which has a similar structure and property to the carbitol form of anthocyanins (Jurd, 1964; Bridle & Timberlake, 1997). Fumigation with SO₂, therefore, has been widely used to minimise browning in harvested litchi fruit. However, surplus SO₂ can bleach the red colour of fruit pericarp to a pale yellow (Holcroft, Lin & Ketsa, 2005) and cause flavour taint (Rattanachai, 1997).

Bleached pale yellow pericarp can be converted back to a red colour by decreasing the pH of pericarp tissue. Hence, acids have been applied to SO₂ fumigated litchi fruit to ensure the uniformity of pink-red colour in pericarp, despite the fact that it confers an unnatural uniform red colouration. Several studies have reported that acid treatments *viz.* tartaric, ascorbic, citric, phosphoric, oxalic and hydrochloric acids (Jiang, Duan, Joyce, Zhang & Li, 2004; Caro & Joas, 2005; Joas, Caro, Ducamp & Reynes, 2005; Sivakumar & Korsten, 2006; Zheng & Tian, 2006; Ducamp-Collin, Ramarson, Lebrun, Self & Reynes, 2008) enhanced red colour in SO₂ treated fruit and minimised litchi pericarp browning during storage. Although many works have documented the mechanism of pericarp browning in harvested litchi, the mechanism of pericarp discolouration in adulterated fruit (i.e. SO₂ and acid treated) has not yet been widely described. Besides, most studies have emphasised only the physiological or biochemical alterations in litchi pericarp rather than in aril tissue (edible portion). The surplus acid and/or SO₂ might impact consumer health and safety (Tongdee, 1994; Rattanachai, 1997) as an injurious residue and could impact on the biochemical composition in aril tissue. The European Community currently allows only 10 µg g⁻¹ sulphur residue in the edible portion of litchi (Ducamp-Collin, 2001). If these effects are deleterious then they might increase demand for unadulterated fruit in the market.

Although perforated polypropylene (PP) is commonly used for litchi, several packaging films have been studied to maintain quality of litchi fruit. Modified atmosphere packaging (MAP) is a complementary method for controlling litchi browning and also has been shown to retain postharvest quality of litchi fruit (Mahajan & Goswami, 2004; Sivakumar, Korsten & Zeeman, 2007; Sivakumar, Terry & Korsten, 2010). According to Somboonkaew & Terry (2010a), MAP not only resulted in higher anthocyanin content and brighter colour in non-adulterated litchi fruit stored at 13°C but also maintained sugar and organic acid concentrations in both aril and pericarp as well as reducing fruit weight loss during 9 days storage. However, no study has yet fully described the effect of the combination of storage temperature and packaging material on both physiological and biochemical alterations in non-adulterated and commercially-treated fruit. Thus, the aim of this study was to investigate the physiological and biochemical changes in pericarp and aril of commercially-treated and non-adulterated litchi fruit as influenced by different packaging films under two different storage temperatures.

2. Materials and methods

2.1 Sample preparation

Litchi cv. Mauritius fruit, grown in Western Galilee, Israel, were exported by Agrexco Agriculture Export Ltd. and imported to the UK (Agrexco, Middx., UK). Fruit were harvested on 6 August 2008. Half of the fruit were fumigated with SO₂ and pre-treated with 19.2 g L⁻¹ citric acid solution for 5 min before being air dried, with the rest

being free from SO₂ and acid. The chemically-treated fruit were referred to as commercially-treated fruit whilst chemical-free regime was considered as non-adulterated fruit. Litchi fruit were freighted to Luxemburg on 7 August 2008 before being transported by refrigerated lorry to the UK on 8 August 2008. Fruit were stored at 1°C before being transported to Cranfield University within 2 h. After being kept at 5°C for 12 h, fruit were sorted for uniformity of size and freedom from defects.

The experiment was arranged as a completely randomised design and was done once at this specific season. The non- adulterated fruit (n = 432) and commercially-treated fruit (n = 432) were divided equally into 144 polypropylene plastic punnets: 140 × 115 mm (Nicholas Ltd., Derbys., UK). The punnetted fruit (non-adulterated fruit 72 punnets; commercially-treated fruit 72 punnets; 6 fruit per punnet) were separated into three groups for packaging treatments. Punnets were then individually placed in either micro perforated polypropylene (PP) bags of 25 µm thickness (Nicholas Ltd.) or 30 µm thickness PropaFresh™ PFAM (Innovia Films Ltd., Cumbria, UK) and sealed using a hand-operated heat sealer (Hulme Martin Ltd., Surrey, UK) whilst the last group remained unwrapped (control). The permeability for moisture vapour and O₂ in PropaFresh™ PFAM film was 3.173×10^{-17} and 7.521×10^{-18} mol s⁻¹ m m⁻² Pa⁻¹, respectively. Packaged fruit were equally separated into two groups for storage at either 5 or 13°C (UK standard shelf temperature and average supply chain temperature, respectively; Catto-Smith, 2006) with *ca.* 68 and 63% RH, respectively. Punnetted fruit were randomly placed on a shelf at 5 or 13°C storage room and sampled after 0, 3, 7, and 11 days. For each outturn, fruits (n = 18) from each treatment were individually weighed and processed. Pericarp colour was determined according to Somboonkaew & Terry (2010) using a Konica Minolta colourimeter (Chroma meter model CR-400 and

data processor model DP-400, Konica Minolta Sensing, Japan), which provided L* (lightness), C* (colour intensity) and hue angle (h° ; 0° = purple-red and 90° = yellow) values. Each value was the average of three measurements from the pericarp surface. Fruit were then peeled, and pericarp, aril tissue and stone separated. Aril tissue was weighed before being gently squeezed to produce a few drops of juice to determine total soluble solids (TSS) using a digital refractometer (PR 301 α , Atago, Japan). To minimise potential contamination of pericarp tissue with aril fruit juice, pericarp tissues were individually washed with distilled water, dried and weighed. Afterward, aril and pericarp tissue were immediately snap-frozen in liquid nitrogen and then stored at -40°C . Frozen aril and pericarp samples were freeze-dried (Coolsafe 55-4, ScanLaf A/S, Denmark) for 9 and 5 days, respectively. Lyophilised samples were subsequently weighed, ground using a hand operated pestle and mortar for aril tissues and a mechanically operated pestle and mortar (RMO mill, Retsch, Germany) for pericarp tissue into a fine powder and stored at -40°C until required.

2.2 Carbon dioxide and ethylene analysis

Both CO_2 and ethylene concentrations (commercially-treated $n = 72$; non-adulterated $n = 72$) in individual PP and PropaFresh™ PFAM bags were measured by applying a silicone rubber disc to the outer surface (on the top) of the bag and then taking headspace gas samples using a needle and 50 mL syringe. For the unwrapped treatment, CO_2 in the storage room was analysed. Each gas sample was immediately analysed for CO_2 according to Somboonkaew & Terry (2010), using gas chromatography (Agilent 6890N Network GC System, Berks., UK). The GC was

calibrated with 10.06 kPa CO₂ in N₂ (Certified Standard from British Oxygen Company (BOC), Surrey, UK). Similarly, ethylene concentrations (commercially-treated n = 72; non-adulterated n = 72) were analysed using gas chromatography (GC model 8340, DP800 integrator, Carlo Erba Instruments, Herts., UK) according to Terry, Chope & Giné Bordonaba (2007). Ethylene was calibrated against 10.6 µL L⁻¹ ethylene in N₂ (BOC).

2.3 Extraction and quantification of sugars

Pooled (from 3 fruit) freeze-dried aril (150 mg; non-adulterated n = 144 and commercially-treated n = 144) was extracted according to Somboonkaew & Terry (2010a) using 3 mL of 62.5:37.5 HPLC grade methanol: water (v/v) and mixed well. Vials of the slurry were placed in a shaking water bath at 55°C for 15 min. They were removed briefly and shaken for 20 s every 5 min to prevent layering, and then left to cool. The cooled samples were filtered through a 0.2 µm Millex-GV syringe driven filter unit (Millipore Corporation, MA) and the clear extract analysed. The extracts were stored at -40°C until required. Sugars were measured according to Somboonkaew & Terry (2010a) using a HPLC system comprising a P580 pump and GINA 50 autosampler (Dionex, CA).

2.4 Extraction and quantification of non-volatile organic acids

Non-volatile organic acids were extracted according to Somboonkaew & Terry (2010a) . Pooled (from 3 fruit) freeze-dried litchi aril or pericarp (50 mg; non-

adulterated $n = 144$; commercially-treated $n = 144$) were mixed well with 3 mL of HPLC grade water. The samples were incubated at room temperature for 5 min and filtered through a 0.2 μm filter and stored at -40°C until required. The extracts were measured using the same Dionex HPLC as previously described before being analysed according to Somboonkaew & Terry (2010a).

2.5 Extraction and quantification of anthocyanins

Pericarp tissue was extracted and quantified according to Giné Bordonaba & Terry (2008) with modifications. Pooled (from 3 fruits) freeze-dried litchi pericarp powder (150 mg; non-adulterated $n = 144$; commercially-treated $n = 144$) was mixed well with 3 mL of HPLC-grade 70:29.5:0.5 methanol:water:HCl (v/v/v). The mixtures were held at 35°C for 1.5 h. They were removed and shaken for 10 s every 15 min to prevent layering. Pericarp extract (20 μL) was quantified using an Agilent 1200 series HPLC (Agilent, Berks., UK) before being measured according to Somboonkaew & Terry (2010a).

2.6 Statistical analysis

All statistical analyses were carried out using Genstat for Windows Version 10.1 (VSN International Ltd., Herts., UK). Analysis of variance was performed on the data, extracting information about the main effects and interactions of storage RH, temperature and storage duration. Least significant difference values (LSD; $P < 0.05$)

were calculated for comparison of appropriate treatment means. Unless otherwise stated differences were significant at $P < 0.001$.

3. Results and discussion

3.1 Fruit weight loss, pericarp moisture content and colour

Fruit weight loss from all treatments increased during 11 days storage but was 1.21-fold higher in non-adulterated fruit. Lower weight loss was observed in commercially-treated fruit, which was in agreement with results recorded in chitosan-citric or chitosan-tartaric treated fruit cv. Kwai Mi (Joas, Caro, Ducamp & Reynes, 2005). Unwrapped fruit had a greater fruit weight loss than those wrapped with PP or PropaFresh™ PFAM films (Fig. 1A). The reduced fruit weight loss in PropaFresh™ PFAM film regimes could be due mainly to the low moisture vapour permeability of this film resulting in slight difference of vapour pressure between fruit and atmosphere in the packages. Similarly, PropaFresh™ PFAM film was reported to minimise weight loss in non-adulterated and SO₂ free litchi fruit cv. Mauritius during 9 days storage (Somboonkaew & Terry, 2010). In the recent study, packaging played a more important role in minimising weight loss of stored litchi fruit than chemical application which was in agreement with Sivakumar & Korsten (2006) who reported that SO₂ or acid treated fruit alone showed greater weight loss than those wrapped with bi-axially oriented polypropylene films. Temperature significantly influenced fruit weight loss, whereby weight loss of fruit stored at 13°C was 1.41-fold and 1.79-fold (for non-adulterated and commercially-treated fruit, respectively) greater than those stored at 5°C. The results

indicated that commercially-treated fruit stored at 5°C in PropaFresh™ PFAM film lost less weight during 11 days storage.

Pericarp moisture content in all treatments declined during storage time but was lower in fruit wrapped with PropaFresh™ PFAM at 5°C (Fig. 1B). Unwrapped fruit at both storage temperatures had significantly lower pericarp moisture content than those wrapped with PP or PropaFresh™ PFAM. Non-adulterated fruit stored unwrapped at 5 or 13°C regimes had lower pericarp moisture content than those commercially-treated fruit. However, wrapping with PropaFresh™ PFAM and PP maintained higher pericarp moisture content in non-adulterated regime than commercially-treated litchi at both storage temperatures (Fig. 1B). There was a negative correlation between weight loss and pericarp moisture content in all treatments for non-adulterated fruit ($r = -0.80$) whilst only a weak correlation was recorded for commercially-treated fruit.

The pericarp of non-adulterated fruit in all plastic film treatments had lower L* (darker) and C* (less colour intensity) with higher h° (more brown colour) values than commercially-treated fruit during 11 days storage (Fig. 2) indicating that the chemical treatment significantly maintained brighter red colour in pericarp of stored litchi fruit, although this colouration was not natural. Pericarp moisture content was positively but weakly correlated with the discolouration of non-adulterated fruit ($r = 0.61$) but not with commercially-treated fruit. Pericarp colour of non-adulterated fruit wrapped in PropaFresh™ PFAM film at both storage temperatures maintained a brighter and more red pericarp colour than those fruit wrapped with PP and unwrapped regimes, respectively. Discolouration of fruit pericarp was significantly delayed by 5°C storage rather than 13°C which was consistent with studies on cvs. Mauritius and Kom (Somboonkaew & Terry, 2010a, 2010b).

3.2 Carbon dioxide and ethylene concentration

Although litchi has been classified as a non-climacteric fruit, elevated concentrations of both CO₂ and ethylene were detected in this study. The PropaFresh™ PFAM packs contained the highest CO₂ and ethylene levels during 11 days storage, followed by PP packs and unwrapped (Fig. 3). The CO₂ concentration in PropaFresh™ PFAM wrapped punnets increased between days 0 and 7 and then declined until the end of storage whilst ethylene increased progressively over the time. The concentrations of CO₂ and ethylene recorded in PropaFresh™ PFAM film regimes could be due mainly to their lower gaseous transmission properties in PropaFresh™ PFAM than PP film. Enhancement of CO₂ and ethylene levels in PropaFresh™ PFAM regimes also could be due partially to increase of fruit senescence during storage time. Increases in ethylene concentrations in PropaFresh™ PFAM wrapped litchi punnets over time has previously been reported by Somboonkaew & Terry (2010). However, CO₂ and ethylene levels in non-adulterated packages in the current study were higher than previous work. This could be due partially to fruit maturity, season and transportation. Non-adulterated fruit wrapped with PropaFresh™ PFAM film resulted in higher CO₂ and ethylene accumulations than commercially-treated fruit. This could be due to an acid impregnation after acid application provided a protective layer on the fruit surface against atmospheric oxygen which decreased respiration rate and led to low CO₂ and ethylene production and accumulation in those packages of commercially-treated fruit. The results implied that CO₂ and ethylene affected the deterioration in stored litchi fruit.. Peng & Cheng (2001) reported that hydrochloric acid treated litchi fruit stored at

4°C had a lower respiration rate ($\text{mg CO}_2 \text{ kg}^{-1} \text{ h}^{-1}$) than those untreated fruit kept under the storage conditions.

There was no disease detected in any treatments during 11 days storage in the current study. This could be because of low pH in commercially-treated fruit pericarp (not measured) which can suppress microbial growth and decay (Brandenburg & Zagory, 2009). For non-adulterated regimes, moderate CO_2 levels combined with moisture in fruit with PropaFresh™ PFAM packages may have resulted in production of carbonic acid in aril and pericarp tissue and consequent decrease in pericarp pH and thus inhibit disease. Alternatively, disease may have not been observed due to low pathogen load. The low moisture content in the pericarp of non-adulterated fruit in PP and unwrapped regimes probably resulted in less suitable conditions for pathogen growth. The current results were in agreement with Somboonkaew & Terry (2010) who reported no disease in non-adulterated fruit stored either in PP or unwrapped at 13°C for 9 days.

3.3 Total soluble solids and sugars concentration

Total soluble solids (TSS) were not significantly affected by storage temperature or time. The TSS content in commercially-treated fruit was higher than in unadulterated fruit which was also observed in litchi fruit treated with phosphoric acid (Jiang, Duan, Joyce, Zhange & Li, 2004) and citric and ascorbic acid (Na Phan, 2007). Unwrapped fruit maintained higher TSS than those wrapped in PP or PropaFresh™ PFAM films, respectively (Table 1). Increases in TSS in stored litchi fruit cv. Mauritius were reported to be minimised by modified atmosphere packaging (Sivakumar & Korsten, 2006;

Somboonkaew & Terry, 2010). This could be due partly to the CO₂ concentration being at ambient levels in unwrapped and PP treatments, which accelerated fruit senescence compared with the PropaFresh™ PFAM packaging. Increase of TSS was also possibly caused by fruit water loss which could contribute to higher concentration of soluble solids in stored litchi fruit. The freeze-dried aril tissue of non-adulterated fruit contained mainly sucrose, fructose and glucose (277.9, 237.5 and 212.5 mg g⁻¹ dry weight (DW), respectively), whilst fructose and glucose (361.4 and 336.0 mg g⁻¹ DW, respectively) were dominant in the aril of commercially-treated fruit with small amounts of sucrose (62.1 mg g⁻¹ DW) (Table 1). Unadulteration and storage at 5°C resulted in a higher concentration of sucrose with lower glucose and fructose concentrations over storage time. Application of acid and SO₂ to fruit coupled with storage at 13°C may possibly accelerate fruit metabolism including sugar invertase enzyme activity which hydrolyses sucrose to glucose and fructose (Chan, Kwok, & Lee, 1975). Transformation of these sugars apparently resulted in higher calculated sweetness ($1.0 \times \text{sucrose} + 0.6 \times \text{glucose} + 1.8 \times \text{fructose}$; Keutgen & Pawelzik, 2008) in commercially-treated fruit. Higher TSS was recorded in commercially-treated litchi in the current study; however, there was no significant difference in total sugar contents according to plastic film treatments, storage temperature and time. In the present study, there was no correlation between TSS and sucrose, glucose, fructose or total sugars concentration. This could be due partly to the small range of changes in refractometric level (15.5-18.3%) in stored litchi fruit.

3.4 Non-volatile organic acids concentration

Malic acid was the major organic acid measured in freeze-dried aril of both commercially-treated and non-adulterated fruit (15.15 and 12.68 mg g⁻¹ DW, respectively; Table 1) with moderate levels of tartaric, citric, oxalic and ascorbic acids. Total acid (malic + tartaric + citric + oxalic + ascorbic acid) content in non-adulterated fruit was significantly lower than in commercially-treated fruit. Higher titratable acidity (TA) was also found in the aril of litchi fruit treated with hydrochloric (Jiang, Duan, Joyce, Zhang & Li, 2004) or phosphoric acid (Sivakumar & Korsten, 2006), whilst citric (Na Phan, 2007) and oxalic acid (Zheng & Tian, 2006) dips did not influence TA in litchi aril. The increase in total acid content or TA in treated fruit could be due to transfer of exogenous acid through pericarp to aril tissue which leads to off-taste and flavour in the aril (Ducamp-Collin, Ramarson, Lebrun, Self & Reynes, 2008). Storage temperature significantly affected organic acids in aril of both commercially-treated and non-adulterated fruit, where fruit stored at 5°C had higher levels of malic, tartaric, citric and total acids (14.62, 6.18, 5.30 and 29.32 mg g⁻¹ DW, respectively) than those stored at 13°C. There was no difference in organic acids concentration according to the plastic film treatments.

3.5 Anthocyanin concentrations

Cyanidin 3-rutinoside, cyanidin 3-glucoside and malvidin 3-glucoside were found in the pericarp of both chemically-treated and non-adulterated fruit. Although higher concentrations of cyanidin 3-glucoside (100.2 µg g⁻¹ DW) and malvidin 3-glucoside (12.54 µg g⁻¹ DW) were detected in non-adulterated fruit, commercially-treated fruit in the current study contained higher cyanidin 3-rutinoside concentrations

(1037 $\mu\text{g g}^{-1}$ DW) which resulted in higher total anthocyanins in commercially-treated fruit. Cyanidin 3-rutinoside was more stable under chemical application and low storage temperatures (Rubinskiene, Viskelis, Jasutiene, Viskeliene & Bobinas, 2005) than the other two anthocyanins analysed. In unwrapped fruit, cyanidin 3-glucoside, cyanidin 3-rutinoside and malvidin 3-glucoside of non-adulterated fruit decreased by 55.7, 40.8 and 49.3 %, respectively between days 0 and 11, whilst reductions of only 38.6, 26.2 and 31.3 % were found in commercially-treated pericarp. This observation suggests that chemical treatment inhibited the reduction of anthocyanin in litchi pericarp tissue. Jiang, Duan, Joyce, Zhang & Li (2004) and Zheng & Tain (2006) found that less browning in stored litchi fruit was closely related to inhibition of PPO and POD activities by exogenous acidity in pericarp tissues rather than degradation of anthocyanins. It is likely that the alteration in pH changed the stability, co-pigmentation and spectra of the anthocyanins found in stored litchi fruit (Joas, Caro, Ducamp & Reynes, 2005). However, Ducamp-Collin, Ramarson, Lebrun, Self & Reynes (2008) reported that all individual anthocyanin concentrations in chitosan-citric treated litchi fruit cvs. Kwai May and Wai Chee were lower than those in non-adulterated fruit due to an increase in PPO, POD and anthocyanase activities over storage time. This inconsistency may be because of the use of different fruit cultivars, acid types, postharvest treatments and storage conditions. In the recent study, fruit from all treatments stored at 5°C contained higher concentrations of all anthocyanins than those held at 13°C. However, storage temperature in the current work apparently was not a dominant factor influencing the anthocyanin alteration as compared to the chemical (SO_2 and acid) treatments (Fig. 5).

Wrapping fruit with PropaFresh™ PFAM film resulted in a higher concentration of all anthocyanins than wrapping with PP or no wrapping during 11 days storage. The

lower content of all anthocyanins in unwrapped fruit could be due mainly to moisture loss causing disruption of cellular compartmentalisation, which accelerates enzymatic activities to form a brown pigment in pericarp tissue (Jiang et al., 2006). However, anthocyanin levels in the present study did not correlate with litchi pericarp colour (L^* , C^* and h°) of chemically-treated and non-adulterated fruit.

4. Conclusions

The investigation clearly implies that PropaFresh™ PFAM film and a low storage temperature of 5°C maintained higher sugar and organic acid contents in aril tissue and higher anthocyanin concentrations in pericarp tissue in both commercially-treated and non-adulterated litchi fruit cv. Mauritius during 11 days storage as compared with unwrapped or PP packaged fruit or 13°C storage. Treatment with SO₂ and citric acid decelerated reduction of aril organic acids and anthocyanins whilst promoting aril sugar transformation. Results also suggest that PropaFresh™ PFAM could replace PP packaging as a new active packaging film for litchi industry and be a substitute for chemical treatment to maintain quality of litchi fruit.

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Figures

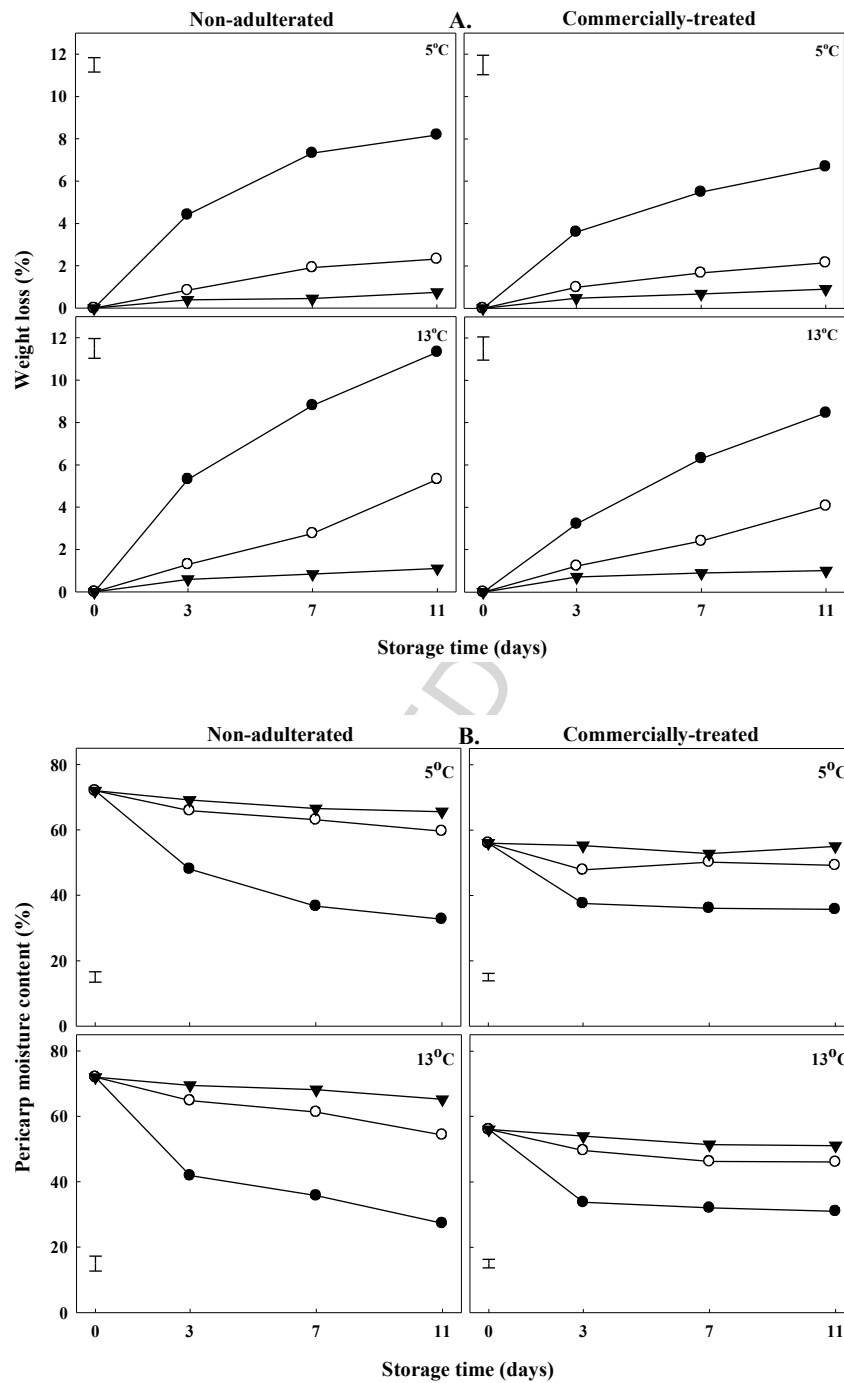


Fig. 1. Weight loss (A) and pericarp moisture content (B) in litchi fruit stored in perforated polypropylene (○), PropaFresh™ PFAM (▼) and unwrapped (●) at 5 or 13°C during 11 days storage ($P < 0.05$).

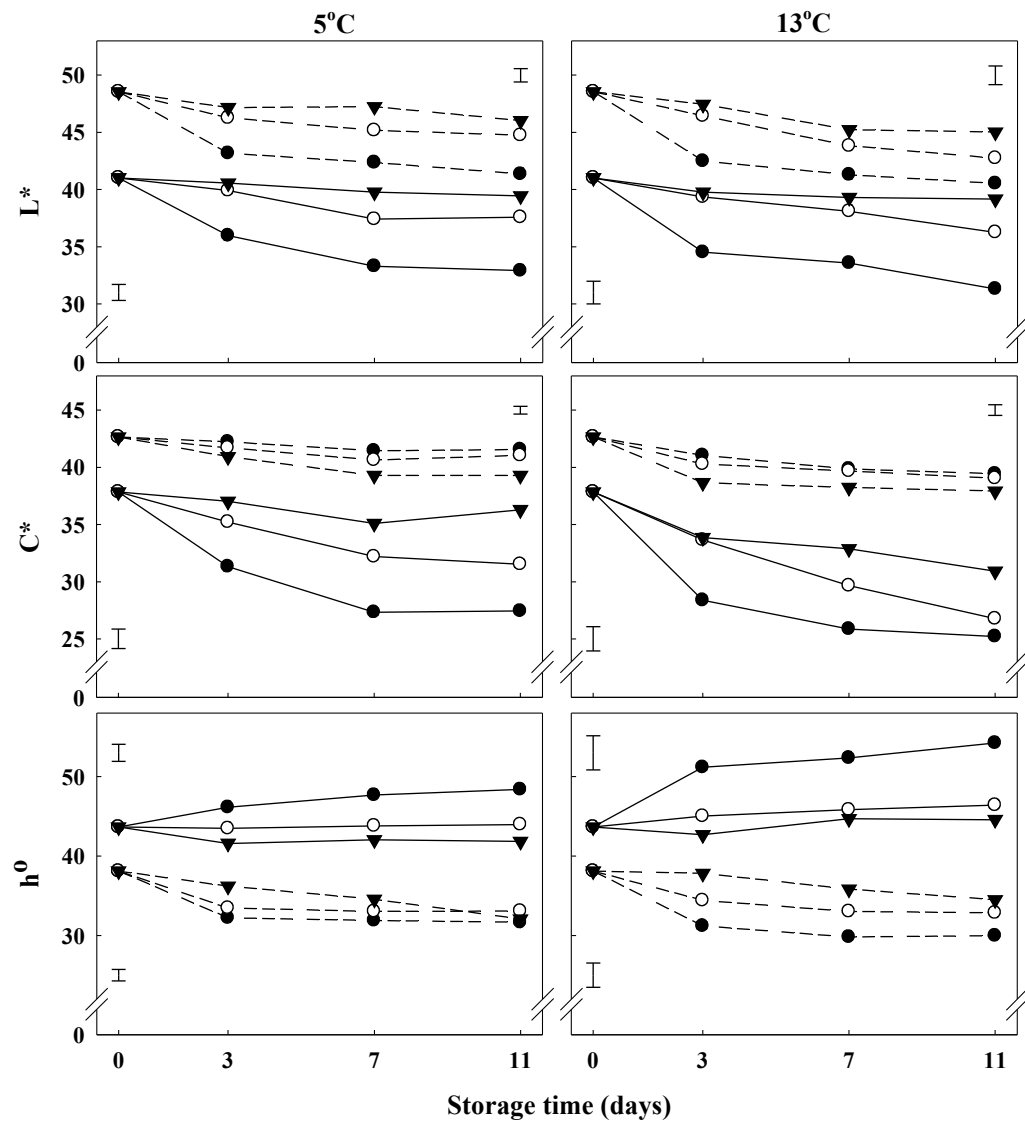


Fig. 2. Pericarp colour (L^* , C^* , h°) of non-adulterated (—) and commercially-treated (---) treated litchi fruit stored in perforated polypropylene (\circ), PropaFresh™ PFAM (\blacktriangledown) and unwrapped (\bullet) at 5 or 13°C during 11 days. ($P < 0.05$).

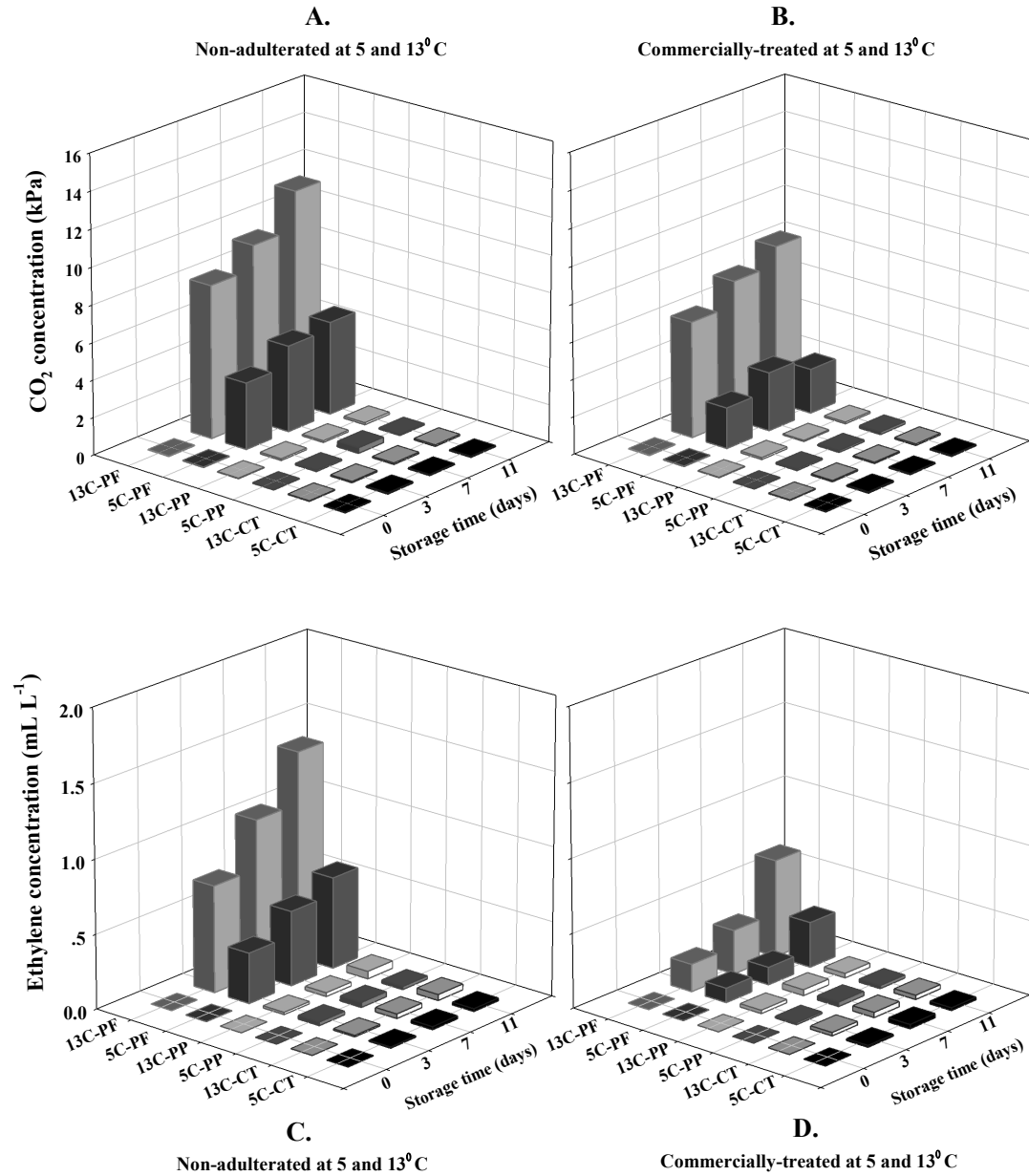


Fig. 3. Carbon dioxide and ethylene concentrations in micro perforated polypropylene (PP), PropaFresh™ PFAM (PF) and unwrapped (CT) during 11 days storage of non acid (A and C) and commercially-treated (B and D) litchi fruit. Each value is the mean of 3 packs.

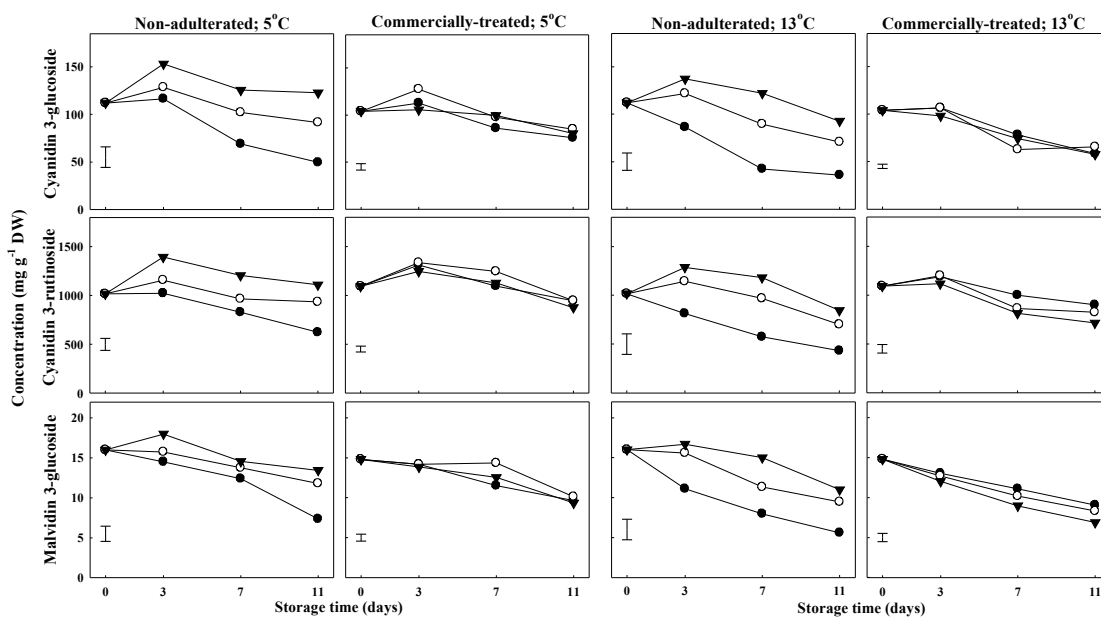


Fig. 4. Anthocyanin concentrations in pericarp of litchi fruit stored in perforated polypropylene (○), PropaFresh™ PFAM (▼) and unwrapped (●) at 5 or 13°C during 11 days storage. ($P < 0.05$).

Table**Table 1**

Total soluble solids (TSS), sugars and organic acids in aril tissue of non-adulterated (N-A) and commercially-treated (C-T) litchi fruit stored in perforated polypropylene, PropaFresh™ PFAM and unwrapped at 5 or 13°C after 0 and 11 days storage.

Packaging	Fruit type	Temperature (°C)	TSS (% Brix)	Sugars (mg g ⁻¹ DW)			Organic acids (mg g ⁻¹ DW)		
				Sucrose	Glucose	Fructose	Ascorbic	Malic	Tartaric
All packaging at day 0	N-A	20	17.23	314.3	228.0	220.0	1.30	23.17	11.00
	C-T	20	17.50	115.0	319.0	323.0	0.95	19.25	9.00
Unwrapped	N-A	5	17.00	272.8	207.3	234.5	1.08	13.19	6.23
	N-A	13	16.81	218.3	232.5	276.3	1.05	11.54	6.87
	C-T	5	18.46	41.1	340.7	367.2	0.61	10.54	3.93
	C-T	13	18.83	27.1	347.2	385.6	0.52	9.06	3.76
Micro perforated polypropylene (PP)	N-A	5	16.34	288.3	204.5	226.8	0.86	15.82	6.64
	N-A	13	16.30	250.2	220.3	255.8	0.72	14.46	6.15
	C-T	5	18.32	46.1	347.5	372.5	0.50	11.86	4.14
	C-T	13	17.84	25.7	345.1	379.5	0.46	10.89	3.73
PropaFresh™ PFAM	N-A	5	16.37	296.1	215.9	244.5	0.86	16.10	7.00
	N-A	13	15.53	268.1	215.1	261.5	0.80	15.53	6.25
	C-T	5	17.76	59.2	339.2	364.4	0.50	12.12	4.52
	C-T	13	18.04	31.7	348.7	375.1	0.29	9.77	3.74
LSD ($P < 0.05$)			0.645	12.21	10.01	8.91	0.656	2.148	1.765
CV (%)			8.1	10.8	6.8	5.5	24.5	16.4	18.6