



Storage and modified atmosphere packaging effects on shelf life qualities of papaya 'Fiji Red' fruit.

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Summary

Two postharvest trials were conducted in Fiji on a solo-type papaya fruit variety ('Fiji Red') between July and August 2012. The trials investigated the effects of several modified atmosphere packaging (MAP) bags and cold storage durations on the subsequent shelf life quality and ripening behaviour of papaya fruit. Papaya fruit were harvested and heat treated using high temperature forced air (HTFA) to 47.2°C for 20 min, followed by a hot water dip at 48°C for 20 min for disease control. In the first trial, fruit were packed and enclosed in a bag liner made of either a (A) LifeSpan type C polyamide film with macro-perforations, (B) a Low Density Polyethylene (LDPE) film with 10 g of KMnO₄, or placed in a (C) carton without a bag (control fruit). In a second trial, fruit were packed and enclosed in either a (A) PeakFresh film, (B) Z106 kiwifruit film, (C) Z108 cherry film, (D) Cling Wrap (a low density polyethylene material), or placed in a (E) sealed carton (without vents) with 10 g of KMnO₄. Fruit from both experiments were then held in cold storage at 10°C for either 3, 2 or 1 week (first experiment) or for only 3 weeks (second experiment) and then assessed over a 9 day shelf life period at 23°C for changes in quality and ripening behaviour.

In the first experiment, headspace CO₂ and O₂ concentrations during all storage durations ranged between 3.8 to 9.4% O₂ and 5.2 to 7.3% CO₂ (LDPE) or were at 18% O₂ and 4% CO₂ (LifeSpan) or stayed at ambient atmospheric conditions of 20.9% O₂ and 0.2% CO₂ (controls). Over the shelf life period, both MAP type and storage duration independently affected colour development, with fruit in LDPE and LifeSpan bags being slightly more advanced (mean 80% colour) than control fruit (62% colour) by Day 6. Only storage duration had an effect on the rate of softening, with fruit held for 2 and 3 weeks being initially slightly softer (rubbery) than control fruit (semi-rubbery). By Day 6, fruit stored for week 1 had surpassed the 2 and 3 week fruit (semi-sprung) and were slightly softer (sprung stage). Over the entire experiment fruit in LDPE lost less moisture (ca. 2-4%) than control fruit (up to 5.5%), whereas moisture loss rates in LifeSpan treated fruit increased with storage duration from 3.7% (1 week) up to 5.7% (3 weeks). Generally, from Day 4 onwards the incidence and severity of disease was high, particularly in fruit stored for 1 and 2 weeks. Analyses on fruit held for 3 weeks showed that MAP had no effect on the incidence or severity of disease, with percent of fruit affected increasing from 28% (Day 4) to 60% (Day 9). MAP type also had no effect on the proportion of fruit that were non-saleable over the 9 day shelf life period, ranging from 16% (Day 4) to 24% (Day 9).

In the second experiment, mean headspace CO₂ and O₂ concentrations in the PeakFresh, Z106 and Z108 bag treatments were similar during storage, averaging between 5-8% CO₂ and 7-9% O₂. Headspace conditions in the Cling Wrap and Sealed Box + KMNO₄ treatments were the same as the ambient environment (20.7% O₂ and 0.3% CO₂). During the shelf life period, skin colouring increased significantly over time, with fruit held in the Z108, followed by the Z106 and Cling Wrap treatments being significantly more advanced (~20-30% more yellow) by Day 4 than fruit in the Sealed Box + KMNO₄ and Peak Fresh treatments (mean 64%). By Day 6, fruit from all treatments, except Peak Fresh (90% colour), had attained full colour. Changes in fruit firmness were not affected by MAP type, with all fruit reaching a 'Sprung' and 'Soft' stage around Day 6 and 9, respectively. During the shelf life period, fruit lost increasingly more moisture with time irrespective of any MAP treatment, losing up to 10.5% of their initial weight by Day 9. MAP type also had no effect on the incidence of disease, with around 26% (Day 4) and 61% (Day 9) of fruit being affected. This equated to a severity of 11% and 23% on these respective days. The MAP treatment significantly affected the proportion of fruit that were saleable, with fruit held in Cling Wrap and Sealed Box + KMNO₄ reaching the lowest number of non-saleable fruit (ca. 13%) by Day 9 compared with the other MAP treatments (33 - 66% not saleable).

A destructive assessment was conducted on Day 6 within the shelf life environment to test fruit for flavour and total soluble solids content (TSSC). MAP type had a significant effect on flavour, with

the highest flavour, in descending order, occurring in the LDPE bag (mean 7.05), followed by the Cling Wrap (mean 6.6), No bag (Control) (6.5) and both Z106 (5.9) and Z108 bags (5.6) treatments. Fruit held in a sealed box with KMNO₄, a Peak Fresh bag or the LifeSpan bag scored an unacceptable flavour (5.5), although no off-flavours in any treatments were reported. TSSC was not related to flavour, with the highest Brix levels (12°) being in the control carton and both Z108 and Z106 bags. Intermediate levels of Brix were recorded in the Cling Wrap, LifeSpan, Sealed+KMNO₄, and LDPE bags (ranging from 11° to 11.8° Brix), and the lowest in the Peak Fresh bags (mean 10.6° Brix).

In closing, fruit with the highest overall quality in the first experiment were those held in LDPE films. These fruit were maintained in a storage environment with CO₂ and O₂ concentrations close to the recommended combination for extending shelf life. LDPE-treated fruit, particularly those stored for 3 weeks, ripened faster during the shelf life (in terms of colour development and Brix levels), had less overall moisture loss and scored high in the flavour assessment compared with the other two treatments. In the second experiment, results were less clear-cut but fruit from Z108 and Z106 bags were generally maintained in a gaseous environment closest to the recommended guidelines for extending shelf life. These fruit also coloured up faster and achieved a high score in the flavour test, although had a high proportion of non-saleable fruit due to decay. In conclusion, the use of an LDPE bag, followed second by a Z106 or Z108 bag, produced the optimum results in terms of quality maintenance during the shelf life period. Future work focused on controlling disease outbreaks would likely ensure higher outturn quality and fruit numbers with the use of these bags.

Introduction

Export of Fijian papaya has increased significantly over the last several years. In 2010, papaya exports were valued at around \$700,000 which, due to increasing international demand, has resulted in a turnover close to \$6 million by the following year (Freshplaza 2012). With demand expected to increase over the coming years, knowledge on the potential supply chain systems capable of delivering fruit to distant markets would be essential. Shipment via sea freight rather than by air already provides significant advantages, such as a reduction in shipping costs and over the long term a minimisation in capacity constraints that are associated with air freight consignments (Campbell et al. 2011).

Recent research on Fijian papaya exports to New Zealand has identified several improvements to the export program. These include both modifications to cartons such as use of air vents for cooling fruit and the use reinforced carton packaging to ensure delivery of sound unripe fruit (Campbell et al. 2011). Sea freight transit times to New Zealand are relatively short (ca. 7 days) compared with other lucrative markets, such as Australia. Estimated shipping times between Lautoka, Fiji and Melbourne, Australia is around 15 days. Longer shipping or handling times however increase the likelihood of fruit spoilage and quality deterioration (Paull et al. 1997). The use of controlled atmosphere containers can provide effective technological solution for extending the life of fruit and vegetables over long transit times (Brecht et al. 2003), although the lack of suitably sized containers out of Fiji has posed constraints (ref).

The use of modified atmosphere packaging (MAP) however may be a suitable and alternative approach to addressing the issue of long transit times (Brecht et al. 2003). Past work has shown that the use of MAP in combination with cool storage (10°C) can successfully extend the storage life of papaya fruit for up to 3 weeks (Gonzalez-Aguilar et al. 2003). MAP extends product storage life by essentially modifying the gaseous headspace environment around fruit, which in turn controls respiration activity and subsequently slows or delays the ripening or senescence process (Kader et al. 1989). Selection of the optimum packaging material however can be problematic given that outturn quality can be affected by a range of issues, including differences in the inherent properties of the fruit per se, eg. differing respiration rates between varieties, fruit size or surface area, physiological maturity and applications of postharvest treatments (Kader et al. 1989, Jobling 2001). External factors may also further complicate or negatively impact outturn quality such as pre and post storage conditions, handling practices, storage conditions and the duration of storage time during transit (Kader et al. 1989, Jobling 2001, Mir and Beaudry 2004).

The aim of this study was to therefore investigate the efficacy of two potential MAP films on the storage and shelf life characteristics of a Fijian papaya fruit (var 'Fiji Red'). A smaller but complimentary experiment using several commercially available MAP films was also investigated. Fruit packed and enclosed within MAP films were stored in a refrigerated shipping container for 1, 2 or 3 weeks to simulate transport conditions and potential shipping times. Post storage evaluations were conducted for up to 9 days to assess treatment effects on shelf life quality. It is anticipated that this study will provide critical information to Fijian exporters on the potential use of MAP for exportation of papaya fruit to Australia.

Materials and methods

Two postharvest trials were conducted at Nature's Way Cooperative Limited, Nadi, Fiji on a solo-type papaya variety ('Fiji Red') between July and August 2012. The trials investigated the effects of several modified atmosphere packaging (MAP) bags and cold storage durations on the subsequent shelf life qualities of papaya fruit. Due to the limited number of fruit available during this time of year, fruit were confined to two experiments, being a large experiment (referred to as "First MAP Experiment") examining two MAP bag types and three cold storage durations, and a less intensive experiment (referred to as the "Second MAP Experiment") with five MAP bag types but with fewer replicate fruit and only one cold storage duration.

First MAP Experiment

Experimental fruit were harvested on 27 July, 3 August and 10 August, 2012 and collected the following day from a single international fruit exporter in Nadi. The fruit from each consignment corresponded to subsequent storage treatment of either 3, 2 and 1 week, respectively. Upon arrival at Nature's Way Cooperative, fruit from each consignment were heat-treated for the purpose of insect disinfestation, using a High Temperature Forced Air (HTFA) unit. For this procedure, fruit were evenly and randomly placed within one of four large porous plastic lugs (size?) and assigned a random slot within the HTFA unit. Fruit were then heat treated for 6 hours until fruit core temperatures had reached and were sustained at 47.2°C for 20 mins.

After treatment, the lugs were carefully removed from the HTFA unit into a secure quarantine environment within the facility. To assist with disease control (Diczbalis et al. 2012), fruit within the lugs were then fully immersed in ca. 300 L of 48°C water for 20 minutes within a 1000 L plastic tank. The tank was fitted with a 1440 rpm water recirculated pump (Orange Pumps Submersible Model SF50) which flowed at a rate of approximately 20L per minute. Fruit were then removed, air dried, transferred into closed cardboard cartons (fitted with air vents) and cooled overnight at ca. 16°C within a refrigerated shipping container.

The following morning, the fruit were unpacked and graded to remove damaged, over-ripe or defected fruit. The remaining fruit were placed in standard commercial 5 kg pack cartons fitted with air vents and assigned to one of three MAP treatments (Plate 1). Treatments consisted of fruit packed and sealed in either a (A) LifeSpan type C polyamide bag with macro-perforations, (B) a Low Density Polyethylene (LDPE) bag containing small paper bag with 10 g of potassium permanganate (KMnO₄), or (C) a carton without a bag (control fruit). The experimental design consisted of five replicate cartons per MAP treatment, with each carton containing 10 experimental fruit. This was repeated three times, one for each storage duration (3, 2 or 1 week) treatment.

Fruit were then stored in a refrigerated shipping container set to an air temperature of 10°C and held, depending on their consignment, for a storage duration of either 3, 2 or 1 week, so that all fruit were removed on the same date (18 August). During this storage period, headspace gas samples from inside the bags (or control boxes without a bag) were extracted to measure respiratory or atmospheric CO₂ and O₂ levels. Gas samples consisted of a 10 ml air sample extracted through a rubber septum placed on the MAP bag (or carton) surface and measured using a portable Oxybaby® M+ gas analyser. Gas samples were taken every 24 hours until gas levels had stabilised and then every three days until completion of the storage period.

Fruit were transferred into a common shelf life environment maintained at an air temperature of 23°C with a relative humidity of approximately 80%. Fruit quality assessments, as described below, were measured immediately after removal from cold storage and approximately every second or third day for up to 9 days while in the shelf life environment.

Second MAP experiment

Experimental fruit were harvested on 27 July 2012 and collected the following day from an international fruit exporter in Nadi and delivered to Nature's Way Cooperative Limited. Fruit were treated to the HTFA and hot water dip treatments at the facility and subsequently handled in accordance with the procedures outlined above for the First MAP Experiment. Fruit were also packed in the same 5 kg pack cartons (with vents) within one of five MAP film treatments (Plate 1). The treatments included a (A) PeakFresh bag, (B) Z106 kiwifruit bag, (C) Z108 cherry bag, (D) fruit wrapped in Cling Wrap (a low density polyethylene material), or (E) a sealed carton (without vents) and with 10 g of potassium permanganate (KMnO₄). The experimental design overall consisted of three replicate cartons for each MAP treatment, with each carton containing nine replicate fruit.

Fruit were stored for three weeks under the same refrigerated and subsequent shelf life conditions described in the First MAP Experiment section. During cold storage, the CO₂ and O₂ headspace measurements were also taken in accordance to the procedures described above. Fruit quality measurements were taken over the subsequent 9 day shelf life period.

Fruit quality assessments

Fruit quality measurements recorded every second or third day included papaya skin colour, flesh firmness, fresh weight, and the incidence and severity of disorders and disease. On Day 6, when fruit were classed as being at an "eating ripe" stage, a sub-sample of fruit were destructively assessed for flavour and Brix.

Papaya skin colour

Fruit skin colour will be assessed on each evaluation day by visually determining the proportion (%) of the total skin surface area that had developed a yellow colour.

Moisture loss and whole fruit firmness

Fruit were weighed on every evaluation day and percent moisture loss was calculated by determining the proportion of weight lost from their initial weight at the start of the experiment. Fruit firmness was determined by applying a mild hand-palm compression on the both sides of the fruit. Fruit were scored using a 5 point scale, where 0 = Hard, 1 = Rubbery, 2 = Sprung, 3 = Soft, and 4 = Very Soft. Fruit with a score of between 2 to 3 were regarded as being at an "eating ripe" stage.

Fruit disease

Each fruit was assessed for symptoms of disease and a measure of disease severity was scored based on an estimation of the percent skin surface area affected. An incidence score was subsequently calculated based on the proportion of fruit per treatment exhibiting symptoms of disease. Fruit with a severity of greater than 5% were considered as being non-saleable.

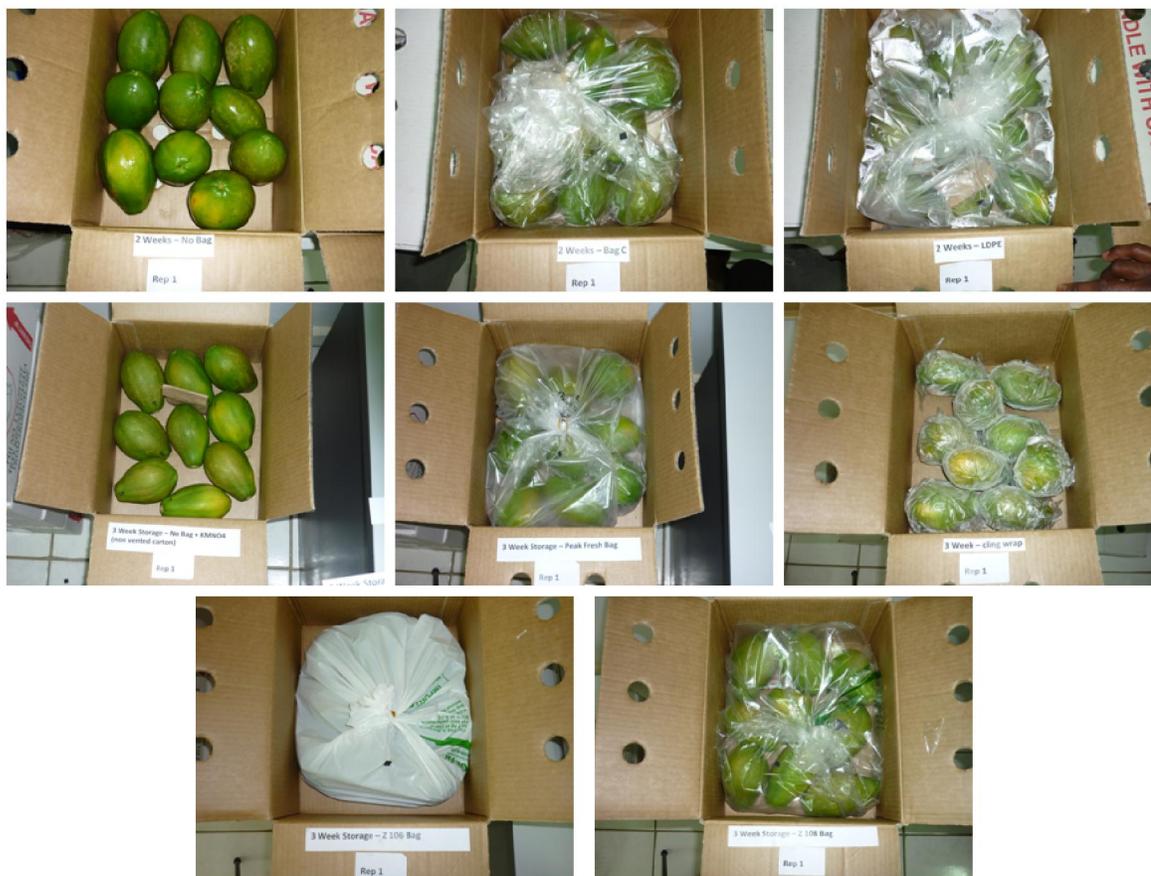


Plate 1. Representative photographs displaying fruit from two experiments enclosed within a MAP bag (except control fruit) within cartons. Top row from left to right comprise MAP treatments from the first experiment: No Bag (Control), LifeSpan C and LDPE + KMNO_4 . Second and third rows, from left to right comprise MAP treatments from the second experiment: No Bag + KMNO_4 , Peakfresh, Cling Wrap, Z106 and Z108.

Fruit flavour and Brix determination

Fruit flavour assessments were undertaken on fruit from the first and second experiments when fruit had reached an “eating ripe” stage. “Eating ripe” was defined as the point when fruit were at >90% colour break with a firmness score of 2 (Sprung stage). Tastings were conducted by 6-7 crop researchers who were familiar with and liked the flavour of papaya fruit. Tasters were presented with a blind composite sample of cubed fruit taken from two to four representative fruit from each MAP treatment (3 week storage treatment only). A tasting event occurred twice on same day, once before (11:30 h) and after a meal (14:30 h). Flesh samples were taken from the lower half of each fruit. Eating quality was score based on a 1 to 9 hedonic scale, where 1 = ‘disliked extremely’, 5 = ‘neither liked nor disliked’ and 9 = ‘liked extremely’. A score below 5.5 was considered to being an ‘unacceptable’ flavour.

Samples of fruit tissue were taken from the same fruit used in the flavour evaluations and analysed for total soluble solids (TSS) content. Juice samples were extracted by manually compressing fruit tissue, with the expressed juice placed onto a refractometer reading plate. TSS content was determined using a portable Atago refractometer with readings expressed in °Brix.

Statistical analysis

Biometrical analyses of fruit quality were conducted using the statistical package Genstat version 11.1 (VSN International Ltd.). A repeated measures ANOVA was performed to test the main and interactive effect of MAP type and cold storage time on each fruit quality attribute over the postharvest shelf life period (main effect of time). In experiments where only one cold storage duration was examined, a repeated measures ANOVA was restricted to only testing the main effect of MAP type. A probability value of 0.05 was regarded as being significant, and not significant results ($P > 0.05$) were reported as “ns”. Differences between treatment levels were determined using a Fisher’s Least Square Difference (LSD) test at 5%.

Results

First MAP Experiment

Headspace gas measurements

In general, headspace CO₂ and O₂ concentrations in the LDPE and LifeSpan bags for the three storage durations began to asymptote after approximately 50 and 100 hours, respectively, while in storage (Appendix). From this point forward, headspace gas concentrations within LDPE bags were within the atmospheric regions theoretically obtainable with a perforated and continuous film type system (Beaudry 1999), with headspace gas levels ranging between 3.8 to 9.4% for O₂ and 5.2 to 7.3% for CO₂ (Figure 1). Mean gas concentrations in the LifeSpan bags were 18% O₂ and 4% CO₂, whereas in the No bag (control) treatment they were not dissimilar to the ambient environment (20.9% O₂ and 0.2% CO₂).

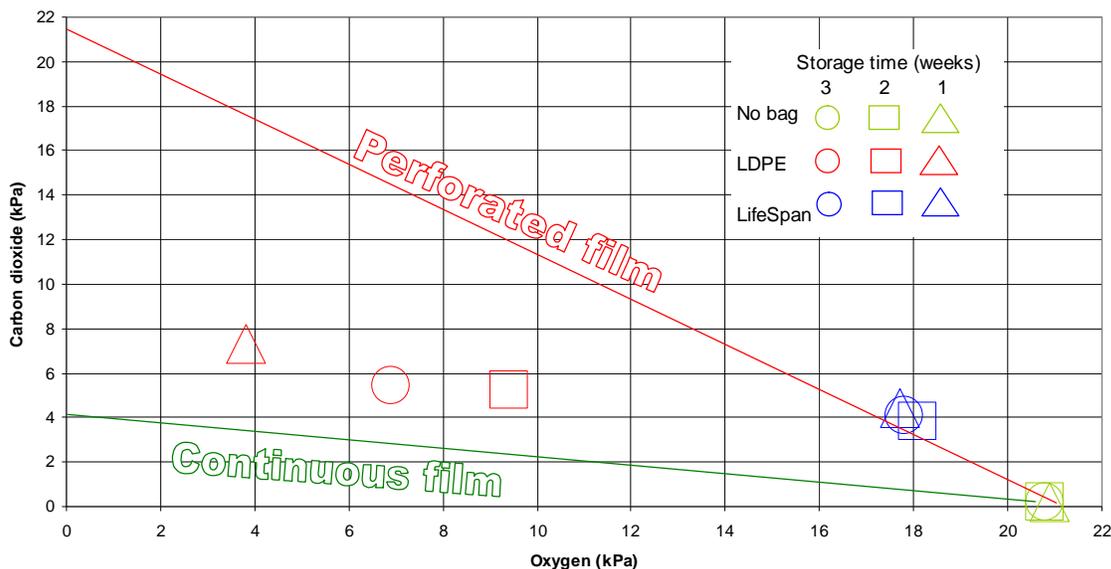


Figure 1. The combination of CO₂ and O₂ gas concentrations in MAP treatments and No bag (control) cartons. MAP treatments consisted of a sealed LDPE film and LifeSpan type C bag with macro-perforations. Papaya fruit held in their respective MAP treatments were held in cold (10°C) storage for 3, 2 and 1 week. The boundary area between the coloured lines represents the atmosphere that is theoretically attainable with the use of a continuous (green line) LDPE film system and one with perforations (red line).

Fruit quality

During the shelf life period, skin colour break increased significantly over time with the main effect of MAP type and storage duration independently affecting colour development (Figures 2A and B). The level of colour break in fruit previously held in LDPE or LifeSpan bags was more advanced than No bag (control) fruit from Day 4 onwards (Figure 2A). In terms of storage duration, fruit stored for 3 weeks were more advanced in regards of colour development compared with those stored for a duration of 1 or 2 weeks (Figure 2B).

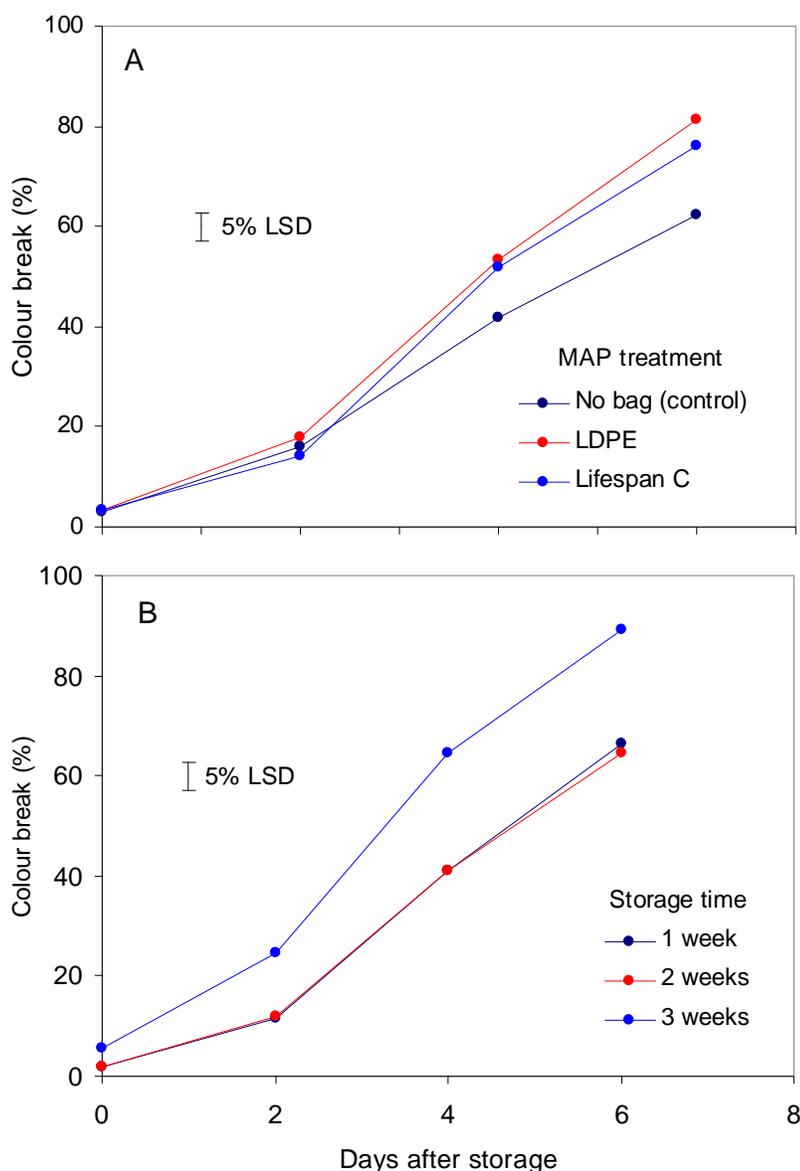


Figure 2. The effect of MAP treatment (A) and storage time (B) on papaya skin colour development following cold (10°C) storage. Papaya fruit were packed in vented cartons within one of two MAP films (LDPE or LifeSpan) or without a packaging film (No bag) and held in storage for either 1, 2 or 3 weeks. Assessments were conducted over a shelf life period of 6 days at 23°C.

Over the shelf life period, changes in fruit firmness were not affected by MAP type but by storage duration ($P < 0.01$) (Figure 3). In this case, by Day 2 fruit stored for 1 week were initially slightly firmer than those stored for 2 or 3 weeks, although by Day 6 the fruit stored for 1 week had become the softest (sprung stage) compared with the other two storage treatments (semi-sprung stage).

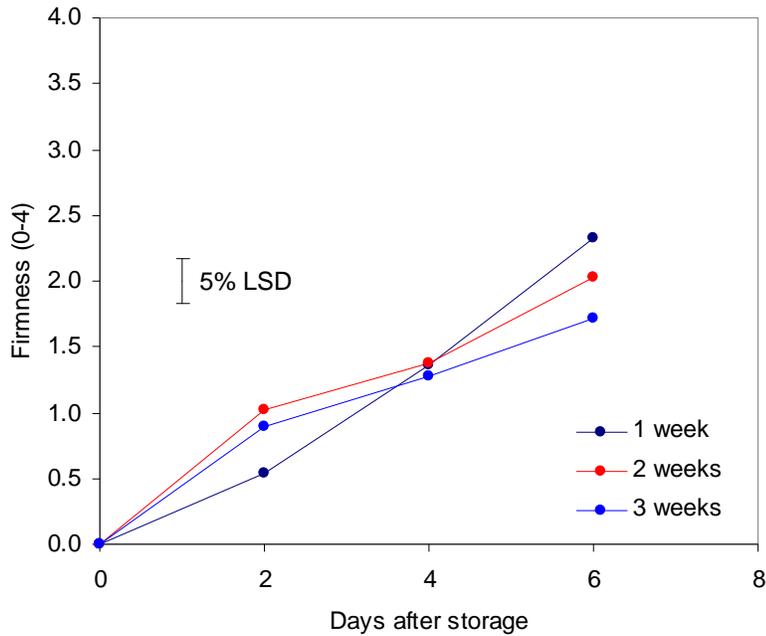


Figure 3. The effect of storage time on fruit firmness of papaya fruit following cold (10°C) storage for either 1, 2 or 3 weeks. Papaya fruit were packed in vented cartons within one of two MAP films (LDPE or LifeSpan) or without a packaging film (No bag). Assessments were conducted over a shelf life period of 6 days at 23°C. Firmness ratings were: 0 = hard, 1 = rubbery, 2 = sprung, 3 = soft and 4 = very soft.

Fruit moisture loss over the shelf life period was not affected by the main effect of MAP type or by storage duration, nor by their interaction. Rather, the combined effects of MAP and storage time treatments was significant when the effect of shelf life time was excluded (Figure 4) ($P < 0.05$). In this case, LDPE fruit generally lost less moisture (ca. 2 to 4%) compared with fruit without a bag (4.5 to 5.5%), while moisture loss in fruit from LifeSpan bags was only lower when stored for 1 week.

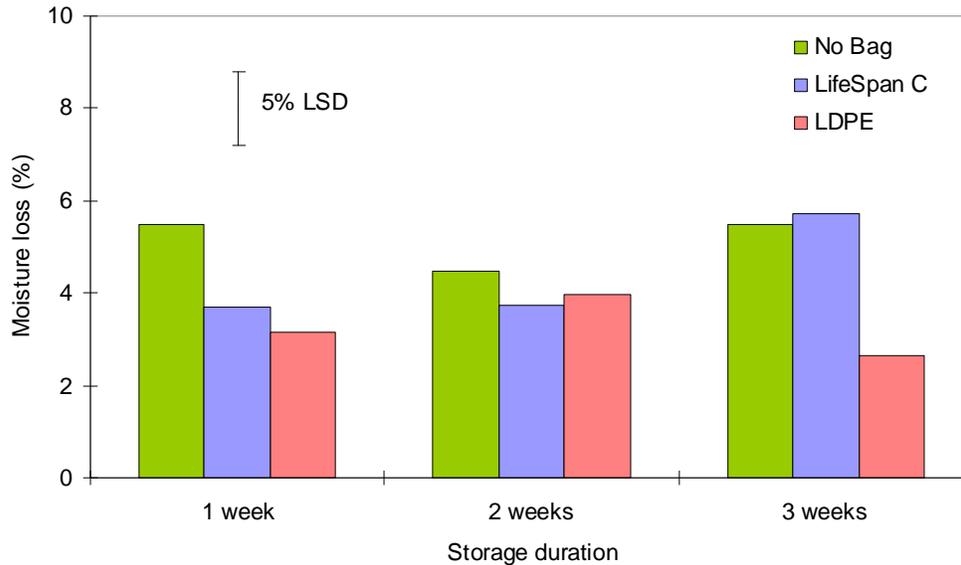


Figure 4. The interactive effect of MAP treatment and cold storage duration on fruit moisture loss averaged over the shelf life period. Papaya fruit were packed in vented cartons within one of two MAP films (LDPE or LifeSpan) or without a packaging bag (No bag) and stored in cold (10°C) storage for either 1, 2 or 3 weeks. Fruit were then assessed over 6 days in a 23°C shelf life environment.

During the shelf life evaluation period, the incidence of disease was extremely high (50 to 90% fruit affected), particularly in fruit stored for 1 and 2 weeks (Appendix). As a result, most fruit in these treatments were discarded from Day 4 onwards. Statistical analyses relating to disease were therefore only conducted on fruit held for the 3 week storage duration. These findings showed that MAP treatment had no effect on either the proportion of fruit affected or on disease severity. On average, around 28% of fruit were affected by Day 4 which increased to 60% by Day 9. Over that period, disease severity ranged from between 10 to 17%.

MAP type also had no effect on the proportion of fruit that were non-saleable (eg. percent of fruit with >5% rots) over the 9 day shelf life period. On average, the proportion of non-saleable fruit on Day 4 and 9 was 16% and 24%, respectively.

Second MAP Experiment

Headspace gas measurements

Similar to the first MAP experiment, headspace CO₂ and O₂ concentrations amongst the various MAP treatments began to asymptote after approximately 50 and 100 hours, respectively, while in storage (Appendix). Mean headspace gas concentrations in the PeakFresh, Z106 and Z108 bag treatments were similar over the remainder of the three week storage period, averaging a CO₂ concentration of between 5 to 8% and an O₂ concentration between 7 to 9% (Figure 5). Headspace gas concentrations in the Cling Wrap and Sealed Box + KMNO₄ treatments were similar to ambient conditions (20.7% O₂ and 0.3% CO₂).

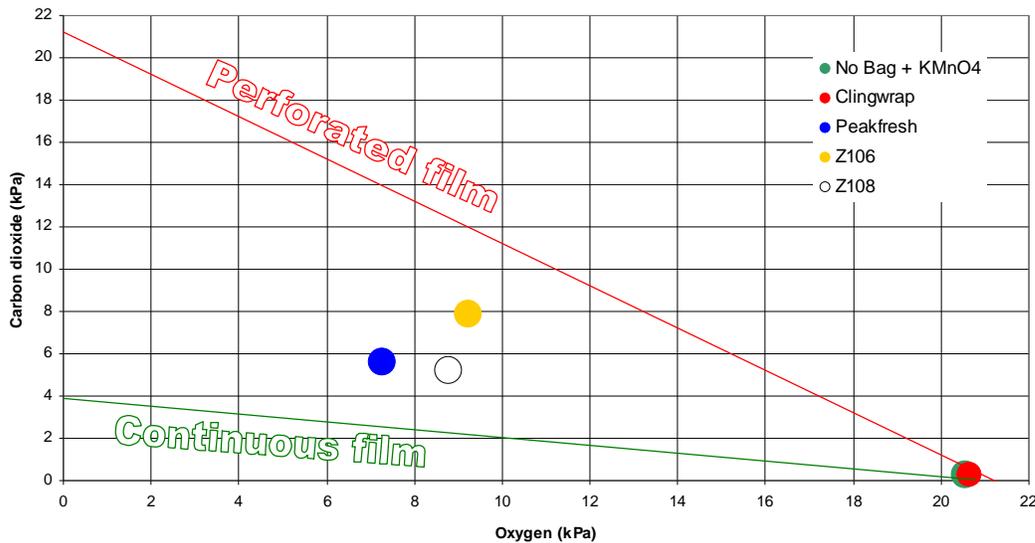


Figure 5. The combination of CO₂ and O₂ gas concentrations in MAP treatments and control cartons (No bag + KMNO₄). MAP treatments consisted fruit wrapped in Cling Wrap or packed in a sealed PeakFresh, Z106 or Z108 bag and held in cold (10°C) storage for 3 weeks. The boundary area between the coloured lines represents the atmosphere that is theoretically attainable with the use of a sealed or continuous (green line) LDPE film system and one with perforations (red line).

Fruit quality

During the shelf life period, skin degreening increased significantly over time, with fruit held in the Z108, followed by the Z106 and Cling Wrap packaging treatments, being significantly more advanced (~20-30% more yellow colour) than fruit in the Sealed Box + KMNO₄ and Peak Fresh treatments (Figure 6). By Day 6, fruit from all treatments, except PeakFresh, had reached a colour break of over 90%.

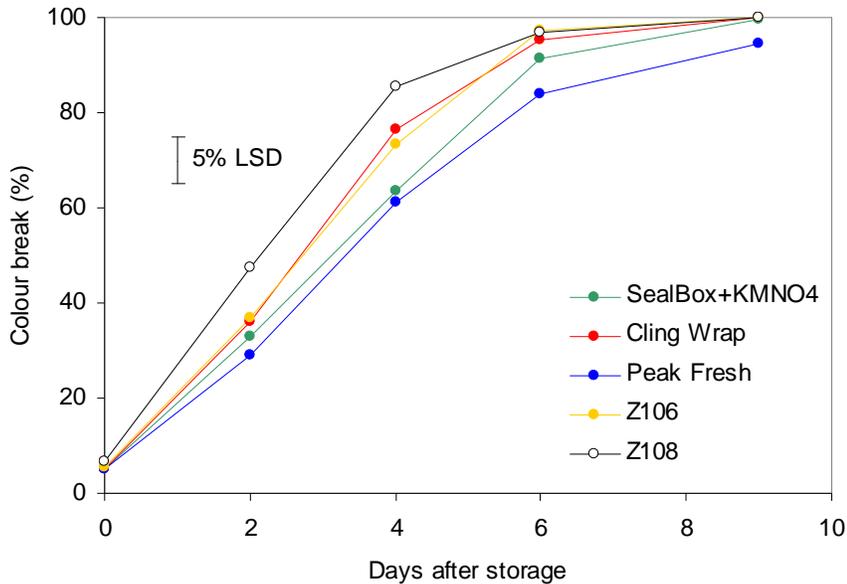


Figure 6. The effect of MAP treatment on papaya skin colour development after 3 weeks in cold (10°C) storage. MAP treatments consisted of fruit either held in a sealed carton with KMNO₄ (SealBox+KMNO₄), wrapped in Cling Wrap or packed in a sealed PeakFresh, Z106 or Z108 bag. Assessments were conducted over a 9 day shelf life period at 23°C.

Changes in fruit firmness were not affected by MAP type, with all fruit reaching a 'Sprung' and 'Soft' stage around Day 6 and 9, respectively (Figure 7A). There was also no significant effect of MAP type on fruit moisture loss during the shelf life (Figure 7B). Over the shelf life period, fruit lost increasingly more moisture with time, losing up to 10.5% of their initial weight by Day 9.

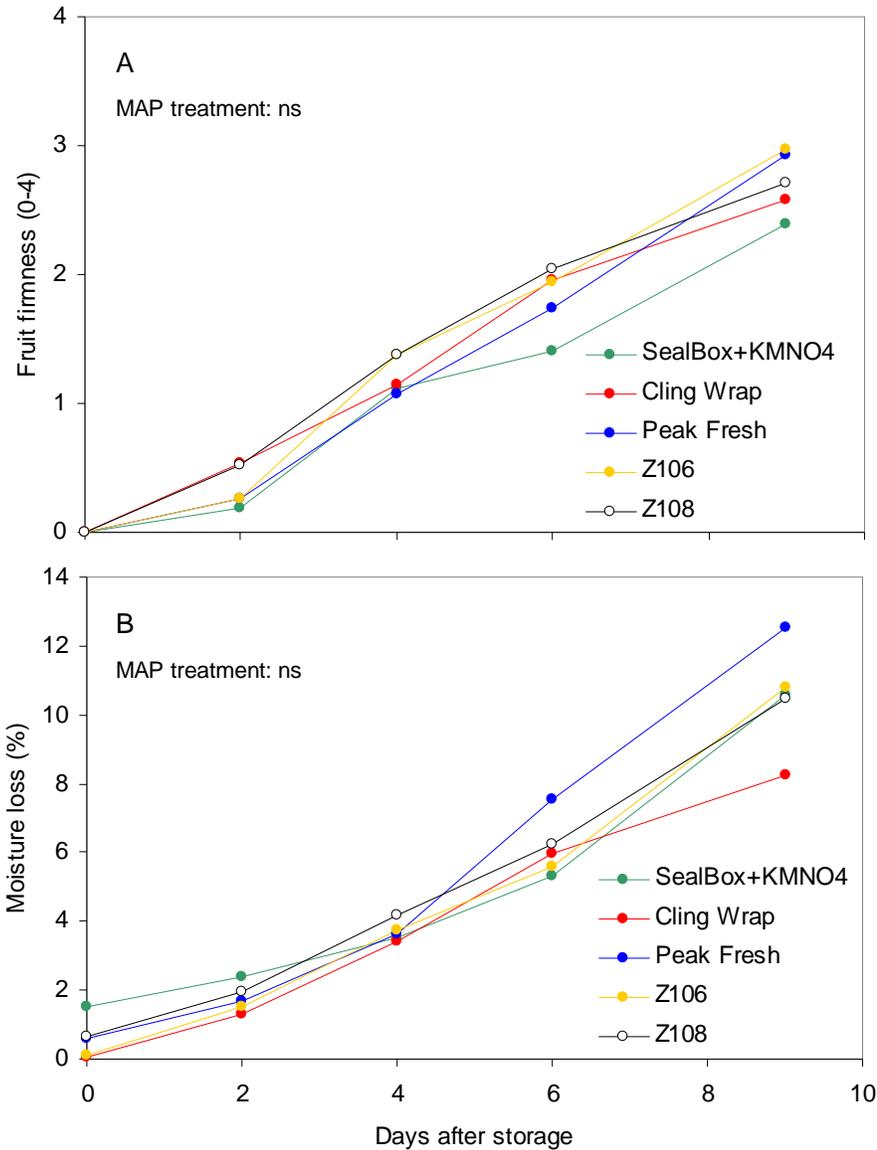


Figure 7. Change in fruit firmness (**A**) and moisture loss (**B**) rates for each MAP treatment after 3 weeks in cold (10°C) storage. MAP treatments consisted of fruit either held in a sealed carton with $KMNO_4$ (SealBox+ $KMNO_4$), wrapped in Cling Wrap or packed in a sealed PeakFresh, Z106 or Z108 bag. Assessments were conducted over a 9 day shelf life period at 23°C. ns = Not significant.

MAP type had no effect on the proportion of fruit that exhibited disease or on the severity of that disease. On average, around 26 and 61% of fruit were affected by Days 4 and 9, respectively. On these days, the level of disease severity was equivalent to 11 and 23%. MAP type did however have an affect on the proportion of fruit that were non-saleable (eg. percent of fruit with >5% rots) over the shelf life period ($P<0.01$) (Figure 8). In this case, fruit held in the Cling Wrap and Sealed Box + $KMNO_4$ packaging treatments exhibited the lowest number of non-saleable fruit by Day 9 (ca. 13%) compared with the other packaging treatments (between 33 to 63%).

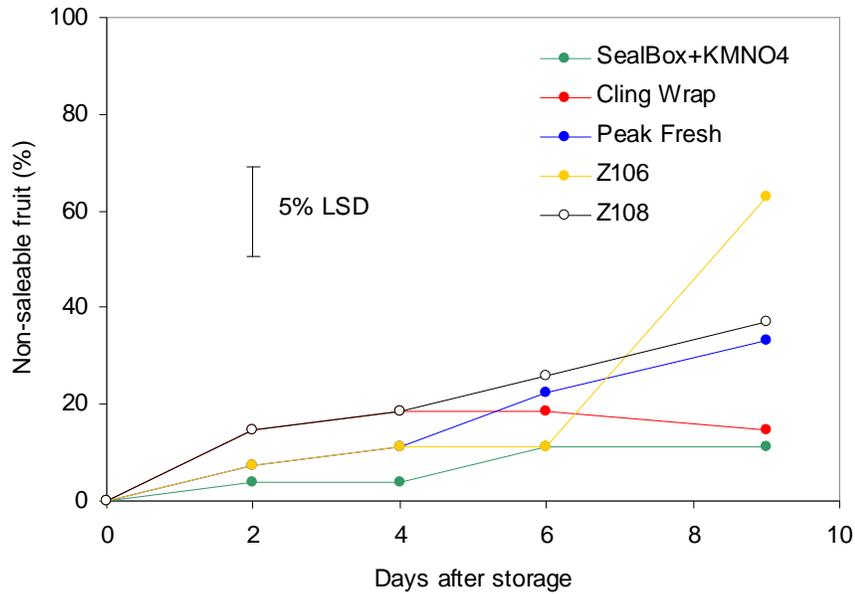


Figure 8. The effect of MAP type on the proportion of non-saleable fruit assessed over a 9 day shelf life period at 23°C. MAP treatments consisted of fruit either held in a sealed carton with $KMNO_4$ (SealBox+ $KMNO_4$), wrapped in Cling Wrap or packed in a sealed PeakFresh, Z106 or Z108 bag and held in cold (10°C) storage for 3 weeks.

Fruit flavour and Brix assessments

MAP had a significant effect on the flavour of fruit on Day 6 of the shelf life period ($P < 0.01$) (Figure 9). The highest flavour response occurred in fruit held in the LDPE bag (mean 7.05) followed, in descending order, by the Cling Wrap (mean 6.6), No bag (Control) (6.5) and both the Z106 (5.9) and Z108 bag (5.6) treatments. Fruit held in a sealed box with $KMNO_4$ (score 5.3), a Peak Fresh bag (score 5.2) or the LifeSpan bag (score 4.6) produced a flavour score equivalent to being “unacceptable”, being below the minimum threshold for acceptability of 5.5. However, no off-flavours were recorded in any of the fruit samples.

Fruit total soluble solids contents was affected by MAP type ($P < 0.05$), despite there being no direct correlation with flavour. Fruit with the highest Brix (12°) were those held in a carton without a bag (Control), followed by both the Z108 and Z106 bags. Intermediate levels of Brix were recorded in the Cling Wrap, LifeSpan, Sealed+ $KMNO_4$, and LDPE bags (ranging from 11° to 11.8° Brix), and the lowest in fruit from the Peak Fresh bags (mean 10.6° Brix).

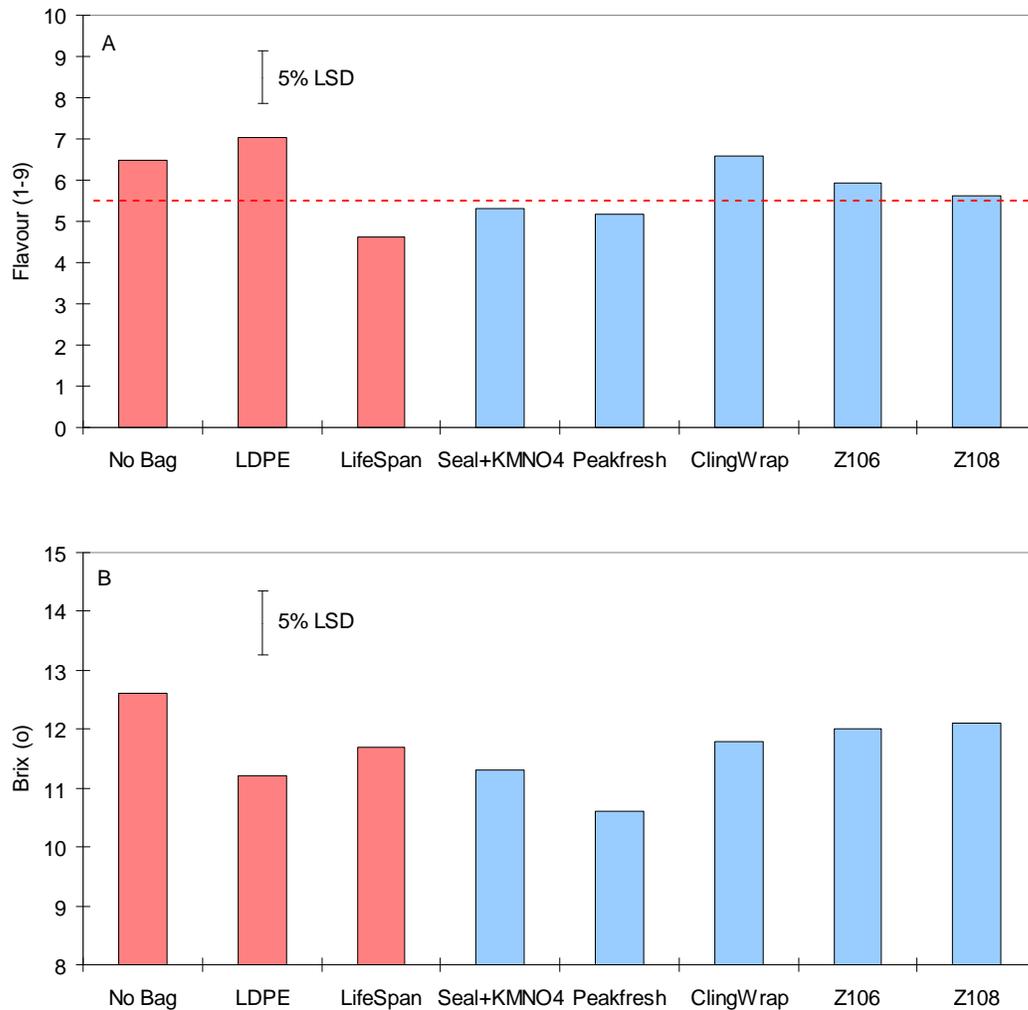


Figure 9. The effect of MAP type on the flavour (**A**) and total soluble solids content (Brix) (**B**) of papaya fruit on Day 6 of their shelf life after 3 weeks in cold (10°C) storage. MAP treatments consisted of fruit selected from the first (red) and second (blue) experiment. The red dotted line (Figure 9A) demarcates the minimum level (score of 5.5) for acceptability for flavour.

Discussion

Optimum controlled atmosphere (CA) conditions for extending shelf life and quality can be achieved in papaya when target headspace gaseous levels of 3-5% O₂ and 5-8% CO₂ are achieved (Kader 1994, UC Davis 2012). The use of MAP can provide several potential advantages such as low cost and ease of implementation (Flores et al. 2004), although achieving optimum gaseous levels are limited by the properties of packaging material used and influenced by various factors associated with the commodity itself (eg. respiration activity, fruit size, maturity), and external factors such as headspace volume, pre and post harvest treatments, and environmental and handling conditions (Kader et al. 1989, Jobling 2001, Mir and Beaudry 2004). In this study, fruit enclosed in the LDPE film (first experiment) and Z108, Z106 and Peakfresh bags (second experiment) achieved a headspace environment that was either similar or near the recommended optimum CO₂ and O₂ concentrations for potential shelf life extension. Within these headspace environments, CO₂ levels attained were closer to the recommended target range (5-8%) than that of O₂. Despite this, the MAP treatments itself did not have any effect on skin colour during storage, which may have been due to the over-riding influence of a low storage temperature of 10°C which suppressed ripening. The fruit also remained hard green in spite of the fact that some treatments (LDPE and Sealed box) were fitted with an ethylene scrubber, an agent known to inhibit ripening or colour development.

After storage, the MAP and storage duration treatments had an impact on ripening behaviour and overall quality. During this period, fruit from both the LDPE and LifeSpan treatments and those stored for the longest storage time (3 weeks) ripened faster in terms of colour development than the control treatment. Interestingly, by the end of the shelf life period fruit stored for the longer storage times (2 and 3 weeks) were firmer than fruit from the 1 week storage treatment. This may have been confounded by the fact most of these fruit (from 1 week storage) had started to develop rots and were thus prone to being softer. In the second experiment, MAP type also influenced post storage ripening behaviour with rates of colour development being highest in the Z108 bag followed by the Z106 and Cling Wrap treatments. Overall, fruit in both these experiments generally reached or were near full colour from Day 6 onwards. Under commercial conditions, post-storage applications of exogenous ethylene (or RipeGas) would have assisted further in accelerating that ripening time while enhancing overall colour uniformity in order to suite specific market conditions.

Fruit moisture loss is well regarded as a factor leading to deterioration of quality, particularly in terms of appearance, texture and nutritional quality (Kader 2000, Jayathunge et al. 2011). In this study, the use of LDPE films in comparison with the LifeSpan or No bag treatment provided the most favourable outcome in terms of the least amount of moisture lost during the shelf life period. In contrast, the rates of moisture loss in fruit from the second experiment did not differ between any of the MAP treatments over the shelf life period. By averaging the daily amount of moisture lost across all treatments and from both experiments, however, a comparative measure of the amount of moisture loss per day can be calculated between experiments. In this case, LDPE fruit (from the 3 week storage treatment) lost approximately 2.6% of their weight in moisture compared with 3% for fruit across all treatments from the second experiment.

Interestingly, fruit held in an LDPE bag recorded a high flavour score, despite there being no relationship to Brix levels. Other treatments which also scored an acceptable flavour score were those held in Z106 and Z108 bags, along with Cling Wrap and No bag (control fruit) treatments. Clearly, the atmospheric conditions in these MAP bags were not conducive to producing off-flavours, which can occur with under excessively high CO₂ (above 8%) or low O₂ (below 2%) conditions (UC Davis, 2012). As the flavour assessment was a minor component in this study, a broader study using more replicated fruit samples would possibly reinforce the findings of this study.

A limitation of this study was the high level of disease amongst most of the fruit, particularly in those from the 1 and 2 week storage treatments. It was possible that environmental factors such as rainy conditions either prior or during harvest predisposed fruit to developing a higher level of rots during the shelf life period, even in spite of an initial postharvest hot water dip treatment. With further control of disease, it would have been possible to monitor fruit quality over a longer shelf life period across all the MAP treatments.

In conclusion, the LDPE bag, followed second by the Z108 and Z106 MAP bag types, generally provided the most favourable outcome in terms of post-storage ripening and quality responses. This study also demonstrated that these fruit were capable of being stored up to 3 weeks without any deleterious effects on quality, being the equivalent amount of time in which fruit could be transited by sea to Australia. Future work needs to consider further methods for controlling disease, particularly if MAP technology is to be considered for an export scenario.

Recommendations

- Fruit exhibited a high level of disease in this study and further measures to control outbreaks would be useful in future studies investigating the use of MAP systems.
- Future studies examining the efficacy of LDPE bags under commercial conditions would likely prove useful, particularly given the cost to manufacture on a per unit basis is relatively low. In this study, LDPE-treated fruit not only ripened faster (in terms of colour development and higher Brix levels) but also lost less moisture and had a high flavour rating at an eating ripe stage.
- Further studies examining the efficacy of Z108 and Z106 bags would be a useful, although the price of individual bags may be more expensive than LDPE bags. Fruit in the Z108 and Z106 bags also coloured up quickly after removal from storage and achieved a high flavour rating, although were prone to increased disease expression.

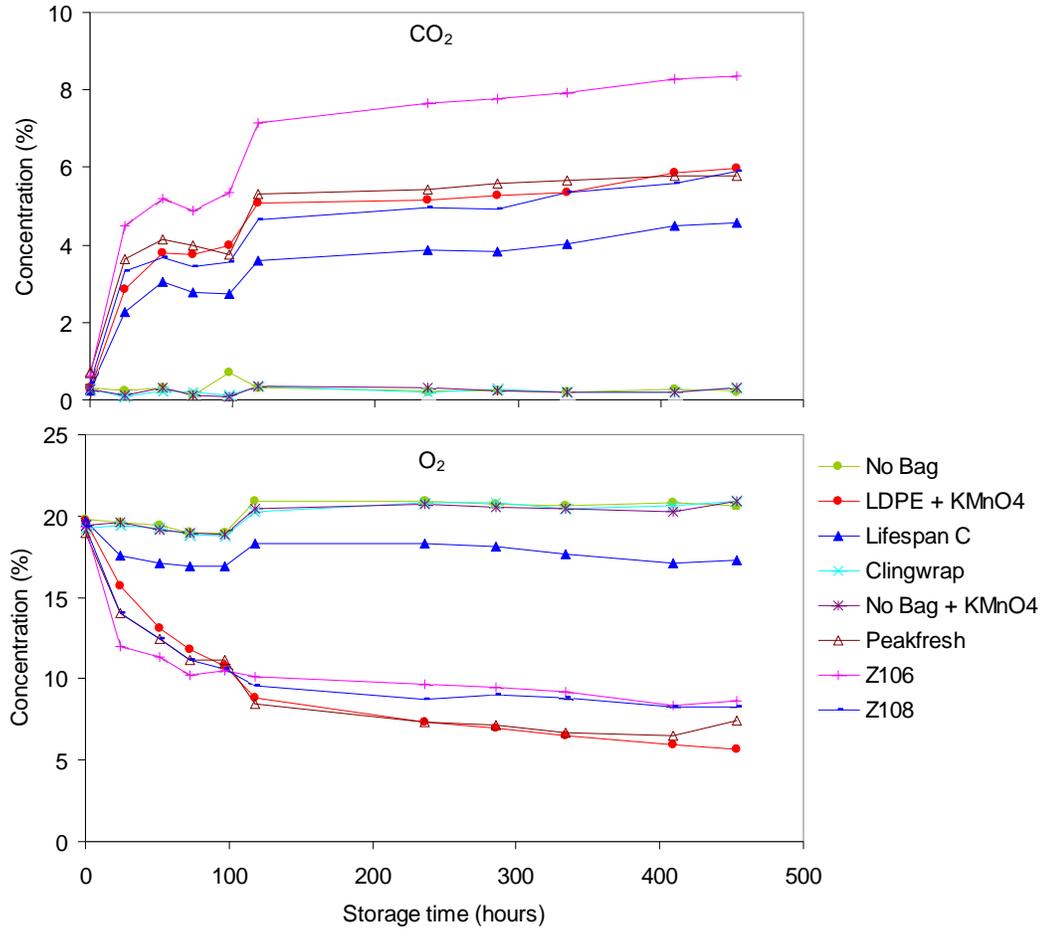
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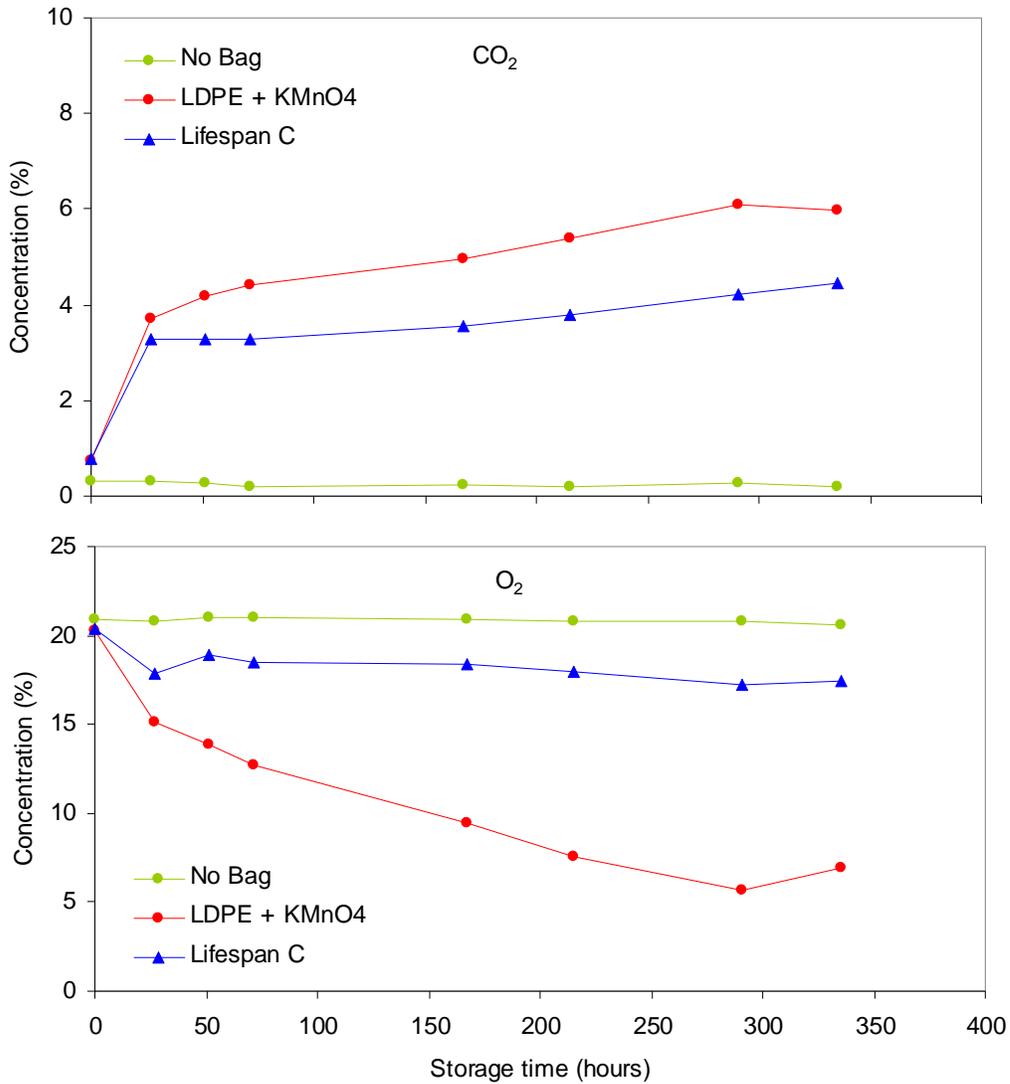
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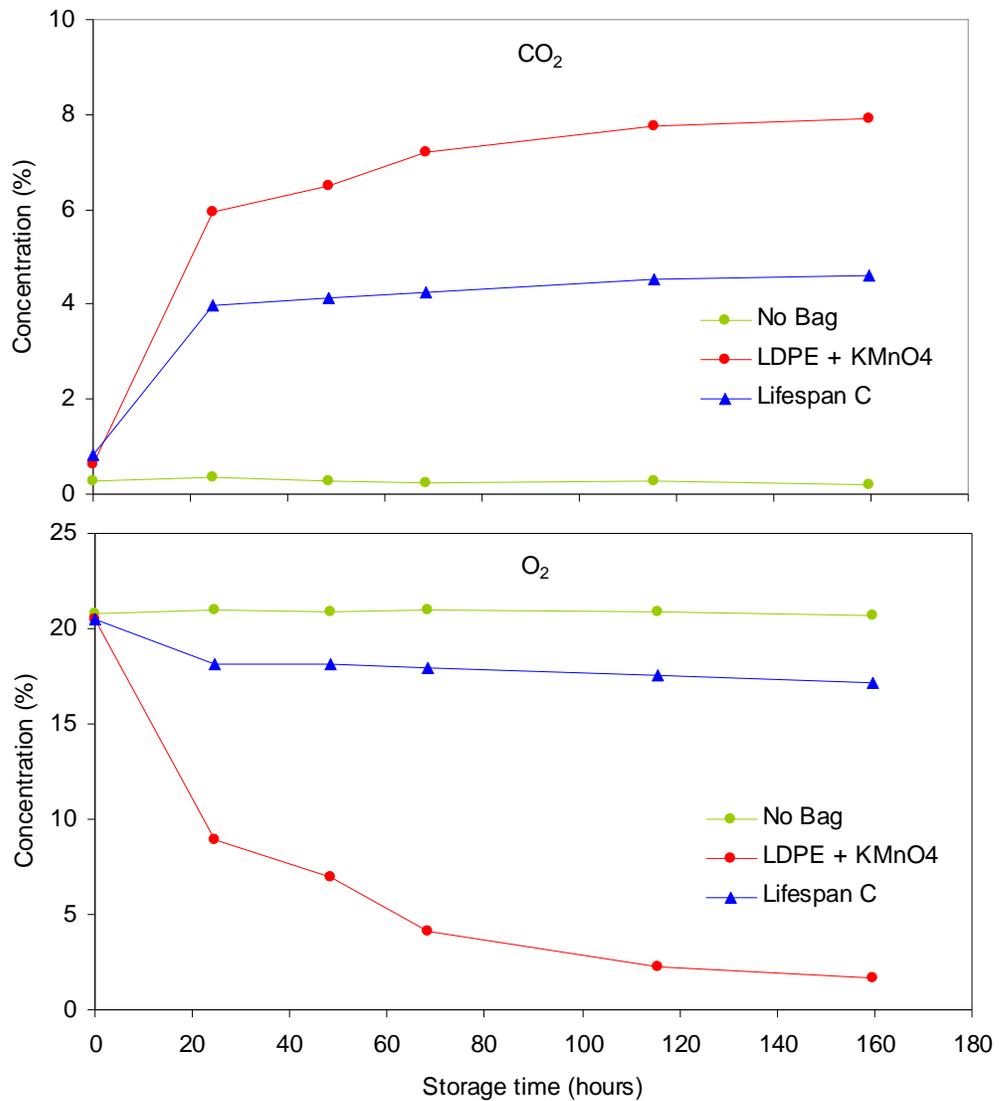
Appendix



Figures. Headspace concentrations of CO₂ and O₂ of papaya fruit stored for 3 weeks at 10°C within various types of MAP bags. Each 5 kg carton held a MAP bag (except “No Bag” treatments) containing up to 10 papaya fruit.



Figures. Headspace concentrations of CO₂ and O₂ of papaya fruit stored for 2 weeks at 10°C within various types of MAP bags. Each 5 kg carton held a MAP bag (except “No Bag” treatments) containing up to 10 papaya fruit.



Figures. Headspace concentrations of CO₂ and O₂ of papaya fruit stored for 1 week at 10°C within various types of MAP bags. Each 5 kg carton held a MAP bag (except “No Bag” treatments) containing up to 10 papaya fruit.

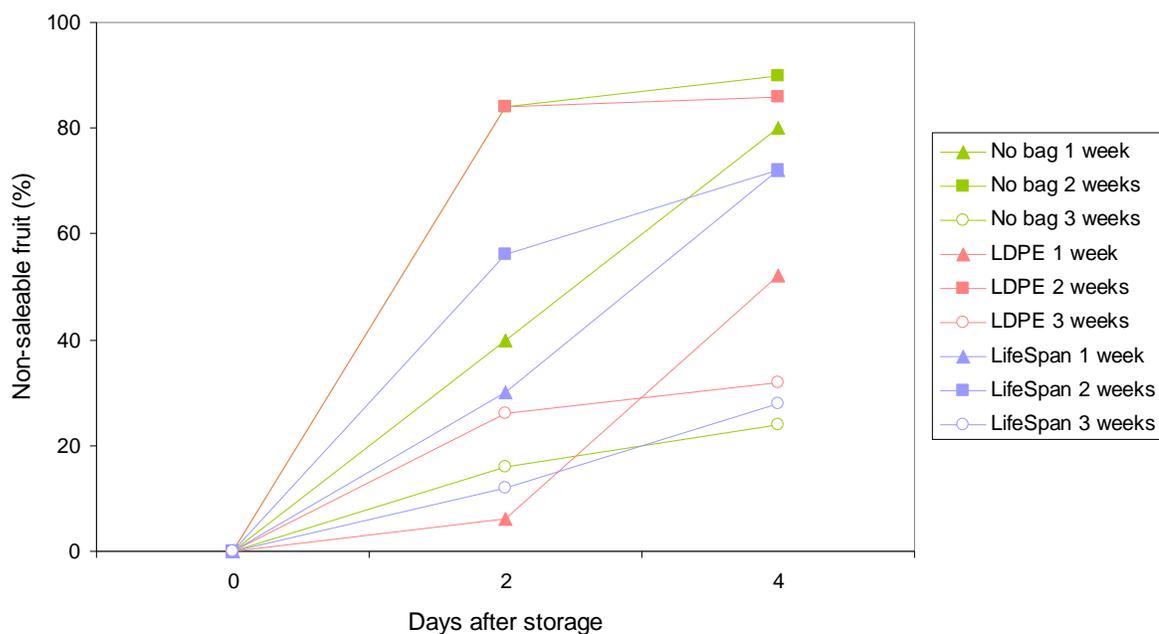


Figure. A non-significant effect of MAP type on the proportion of non-saleable fruit over 4 days in a 23°C shelf life environment. Papaya fruit were packed in vented cartons enclosed within one of two MAP films (LDPE or LifeSpan) or without a packaging film (No bag) and held in storage for either 1, 2 or 3 weeks.