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Postharvest quality and storage life of 'Makapuno' coconut (*Cocos nucifera* L.)

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ABSTRACT

Makapuno is a high-value commercial coconut with distinct sensory attributes, however the postharvest conditions required to maintain quality are unknown. To address this, partially de-husked mature Makapuno coconut fruit were stored at 2, 5 or 30 °C and were then evaluated after transferring to 30 °C for 3 days to simulate conditions in retail markets. During storage at 30 °C, the fruit showed a moderate respiration rate of 40–60 mg CO_2 kg^{-1} h^{-1}, a low ethylene production rate of 0.6–0.8 μL C_2H_4 kg^{-1} h^{-1} and storage life was 3 days. In contrast, storage at 2 °C or 5 °C markedly reduced respiration rates to 4 and 20 mg CO_2 kg^{-1} h^{-1}, respectively, and storage-life increased dramatically from 3 days to 6 weeks. Generally, cold storage delayed fruit deterioration by limiting weight loss, kernel browning and malondialdehyde content, however, after the fruits were transferred to 30 °C, those previously held at 2 °C showed signs of chilling injury, while those held at 5 °C did not. Modified atmosphere packaging (MAP) using high oxygen transmission rate (OTR) bags in combination with 5 °C storage extended fruit storage-life 20-fold, from 3 days at ambient conditions to 10 weeks. The combination of MAP and 5 °C storage reduced weight loss (4-fold), the incidence of surface mold and the quality parameters measured were comparable to values in freshly harvested fruit.

1. Introduction

Makapuno is a specialty coconut of exceptional sensory quality. Unlike most commonly occurring coconuts, the edible solid endosperm often called the 'meat' or 'kernel' is thicker, with a soft jelly-like texture at maturation. This can be attributed to some unusual physiological and biochemical traits. Makapuno contains high levels of cytokinins which promotes cell proliferation and expansion that results in greater endosperm thickness compared with normal coconuts (del Rosario and de Guzman, 1981; Islam et al., 2009). The unlimited growth of the solid endosperm makes Makapuno a model system for tumorigenesis studies in higher plants (Abraham et al., 1965). Makapuno also lacks α-galactosidase activity which leads to the accumulation of higher levels of the water-soluble galactomannan rather than the water-insoluble mannan found in normal coconuts (Mujer et al., 1984). This likely alters cell wall structure and adhesion and produces a highly viscous endosperm (Balasubramaniam, 1976; Mujer et al., 1984). Finally, Makapuno has a higher content of moisture and protein in the endosperm but lower crude fat; the latter trait should reduce rancidity which is important to those food processing industries that use coconut in their products (Adriano and Manahan, 1931; Mujer et al., 1984; Santoso et al., 1996). These features of the Makapuno coconut (so named in The Philippines) are similar to 'Kopyor' in Indonesia, 'Dikiri Pol' in Sri Lanka, 'Thairu thengai' in India (Menon and Pandalai, 1958), Maphrao Kathi' in Thailand and Dua Dac Ruot in Vietnam (Janick and Paull, 2008), and are all known for their combination of good taste and unique 'meat' texture (COGENT, 2008).

The unique endosperm of Makapuno may be controlled by a single Mendelian recessive mutation (*mmm*) (Mujer et al., 1984). The described traits are only found in the triploid endosperm and all alleles need to be recessive. Makapuno therefore need to be physically segregated from normal coconut trees to prevent cross-pollination. In addition, the highly viscous nature of the inner endosperm makes germination difficult. The need for a triploid

Abbreviations: C_2H_4, ethylene; MDA, malondialdehyde; MAP, modified atmosphere packaging; RH, relative humidity; TBA, thiobarbituric acid.

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Fig. 1. *External and internal features of partially de-husked Makapuno coconut after storage.* (A) Partially de-husked mature Makapuno coconut fruit showing the remnants of the mesocarp (husk) and the endocarp for protecting the soft eye from disease invasion. (B) The solid endosperm (meat) was thick, soft and filled about 75% of the cavity; the liquid endosperm increased in viscosity and filled the rest of the cavity (not shown). (C) Deterioration of the coconut stored longer than 3 days at 30 °C showing discoloration and altered texture of the meat.

homozygous recessive state and the observed low germination frequency makes Makapuno coconuts a rarity in nature. The result is a sale price that is 3–5 times higher than normal coconuts in South East Asia (COGENT, 2008) and that can be 50 times higher than that of normal mature coconuts in Thailand.

Although Makapuno is a value-added commodity, to our knowledge, the postharvest behavior of its fruit has not yet been studied. This is important because of the increased demand for fresh coconut fruit in distant markets in Europe and the United States (Mahr, 2012). Previous work showed that normal mature coconut can be stored for 3–5 months postharvest under ambient atmosphere, after which, the liquid endosperm evaporates and the embryo germinates (McGregor, 1987; Paull and Ketsa, 2004; Siriphanich et al., 2011). De-husked mature coconut has a shorter storage life: up to 2 months at 0–1.5 °C, or 3 weeks at 12–15 °C (McGregor, 1987; Muliyar and Marar, 1963; Siriphanich et al., 2011). Although removal of the husk reduces shelf-life, the cost-benefit analysis is better. These fruit weigh less which lowers long-distance shipping costs and the price can be marked-up as the product is more convenient for the consumer. As described, Makapuno fruit has distinct properties compared to normal coconuts and this would be expected to influence the storage performance and conditions used to maintain its quality. The overall goal of this study therefore, was to provide basic information on the storage conditions needed to prolong Makapuno coconut storage-life.

2. Materials and methods

2.1. Postharvest performance of Makapuno coconut

Fully mature Makapuno coconuts (10–11 months from flowering) were partially de-husked, leaving a layer of fiber 1–2 cm thick (Fig. 1a) and were transported from Kanchanaburi province to the laboratory at Kasetsart University within 2 days of harvest. Six uniform and damage-free coconuts were packed in strong well-ventilated fiberboard cartons with dividers to separate individual fruit and were then stored at 30 ± 2 °C, 66 ± 5% relative humidity (RH). Individual fruit was examined for respiration rate, ethylene production rate, weight loss, color, total soluble solid contents (SS), titratable acidity (TA) and lipid oxidation of coconut meat expressed as malondialdehyde (MDA) values and decay at the initial day and 3 days after storage.

2.2. Storage conditions

To study the effect of storage temperature on respiration and ethylene production rates, Makapuno coconuts were handled as described in Section 2.1 and were then held at 2, or 5 °C with 80–85% RH. The quality parameters measured included weight loss, color, SS, TA, MDA, and decay, and were assayed every 2 weeks, immediately after removal from cold storage and after transfer to 30 °C for additional 3 days.

To study the effect of modified atmosphere packaging (MAP) on storage life, 120 Makapuno coconuts were packed individually in a high oxygen transmission rate (OTR) plastic bag (a gift from the National Metal and Materials Technology Center; MTEC, Thailand). The properties and specifications of the bag included (i) size = 0.3 × 0.25 m; (ii) thickness = 22–23 micron; (iii) oxygen transmission rate = 13,500 c $m^3\ m^{-2}\ day^{-1}$; (iv) carbon dioxide transmission rate = 47,000 $cm^3\ m^{-2}\ day^{-1}$ and (v) water vapor transmission rate = 25 $g\ m^{-2}\ day^{-1}$ at 25 °C. Makapuno coconuts quality and storage life were observed as mentioned above.

2.3. Respiration and ethylene production rates

A single fruit was placed in a 3000-mL jar and closed for 90 min then held at 2, 5 or 30 °C. At the indicated time, a 1-mL of headspace gas was withdrawn to measure carbon dioxide (CO_2) concentration indicating respiratory activity and another 1-mL of gas was measured for ethylene production rates. Afterwards, the system jar was opened and left so until the next measurement. CO_2 and C_2H_4 concentration was measured using a gas chromatograph (Shimadzu GC-8A) equipped with a Porapak Q column (CO_2), a thermal conductivity (CO_2) or a flame-ionization (for C_2H_4) detector. For CO_2 determination, Helium was used as a carrier gas, and the injector/column temperature was set at 150 and 70 °C, respectively. For C_2H_4 determination, N_2 was used as a carrier gas and the injector/column temperature was set at 200 and 80 °C, respectively.

2.4. Atmospheric compositions within high OTR bag

The oxygen (O_2), CO_2 and ethylene content within each high-OTR bag was determined as described in Section 2.3. Gas samples were withdrawn from each high-OTR bag using a 1-mL plastic syringe inserted into the gas-sampling septa. Atmospheric compositions within packages, disease ratings and Makapuno coconut qualities were determined every 2 weeks for 10 weeks. Methods and instruments were the same as in the previous experiment.

2.5. Coconut quality

Fruits were assessed for percent weight loss, endosperm color, TSS, TA and were scored for signs of decay. Percent weight loss was calculated by weighing fruit individually before and after storage

and then, expressing the difference as a percent of the initial weight. The color of the coconut meat (solid endosperm) was determined using a Minolta Colorimeter (Model CR-200, Minolta Corp., Ramsay, NJ), and expressed as color space L^*, a^* and b^* mode. Total soluble solids (SS) of coconut water (liquid endosperm) was determined using a hand refractometer (Atago, model ATC-1E, Japan) and titratable acidity was estimated according to the (AOAC, 2000) method using 0.01 N sodium hydroxide (NaOH) with phenolphthalein as an indicator.

Decay evaluation of coconut was assessed using a 5-point scale ranging from 1 to 9. On this, scale 1 = free of decay, 3 = fungal spore appearance on less than 25% at the shell (exocarp) but the meat is free of decay, 5 = fungal spore appearance on 25–50% of the shell but the meat is free of decay, 7 = fungal spore evident on 50–75% of the shell and the meat shows minor deterioration, 9 = fungal spore evident on more than 75% and the meat shows deterioration.

2.6. Malondialdehyde (MDA) measurements

The solid endosperm (2 mg) was reacted with 10 mL of 10% (w/v) thiobarbituric acid (TBA) before homogenization, and was then centrifuged (12,000 × *g*, 15 min) at 4 °C to remove insoluble material (Cakmak and Horst, 1991). A 1-mL aliquot of the supernatant from each homogenized sample was placed into a microcentrifuge tube then gently mixed with 3-mL of 0.5% (w/v) TBA by vortexing. The sample was incubated at 100 °C for 10 min, and was then cool to 25 °C before the absorbance at 532 and 600 nm was measured. The amount of MDA was expressed in equivalents in nmol per mL using the equation as followed:

$$\text{concentration of MDA (nmol/mL)} = \frac{(A_{532} - A_{600})}{155} \times 10^6$$

where A_{532} is the absorbance at 532 nm, A_{600} is the absorbance at 600 nm.

2.7. Statistical analysis

The analysis of variance and significant differences among means were analyzed with SPSS statistical package (16.0 Version) at 95% confidence level ($P \leq 0.05$).

3. Results

3.1. Changes in Makapuno coconut fruit quality after harvest

At harvest, average fruit weight was 800–1000 g. The exocarp (thin hard, outer skin) of the fruit was mostly brown with minor green patches and the fibrous mesocarp (husk) was brown and thick. At this stage, the semi-solid endosperm filled about 25–50% of the cavity with the remaining volume taken up by the thickened liquid endosperm (the coconut water) (Fig. 1). When stored at 30 °C, the partially de-husked Makapuno coconut maintained good quality up to 3 days of storage and thereafter deterioration occurred. Visual evidence included disintegration of the coconut meat, fungal attack, and the coconut water turned yellow (Fig. 1). Weight loss of the partially de-husked fruit after 3 days of storage was low, approximately 2% of initial weight. The rates of respiration and ethylene production were approximately 40–60 mg CO_2 kg^{-1} h^{-1} and 0.6–0.8 μL C_2H_4 kg^{-1} h^{-1}, respectively (Fig. 2). At harvest, TSS, TA and malondialdehyde (MDA) contents of the coconut meat were 5 °Brix, 0.03% and 155 nmol mL, respectively. There was no statistical change in these parameters after 3 days of storage at 30 °C ($P > 0.05$). The color of the meat at harvest was bright white and the b^* value decreased from 1.05 to −0.96 indicating a slightly bluer hue, while the L^* and a^* did not change (Table 1).

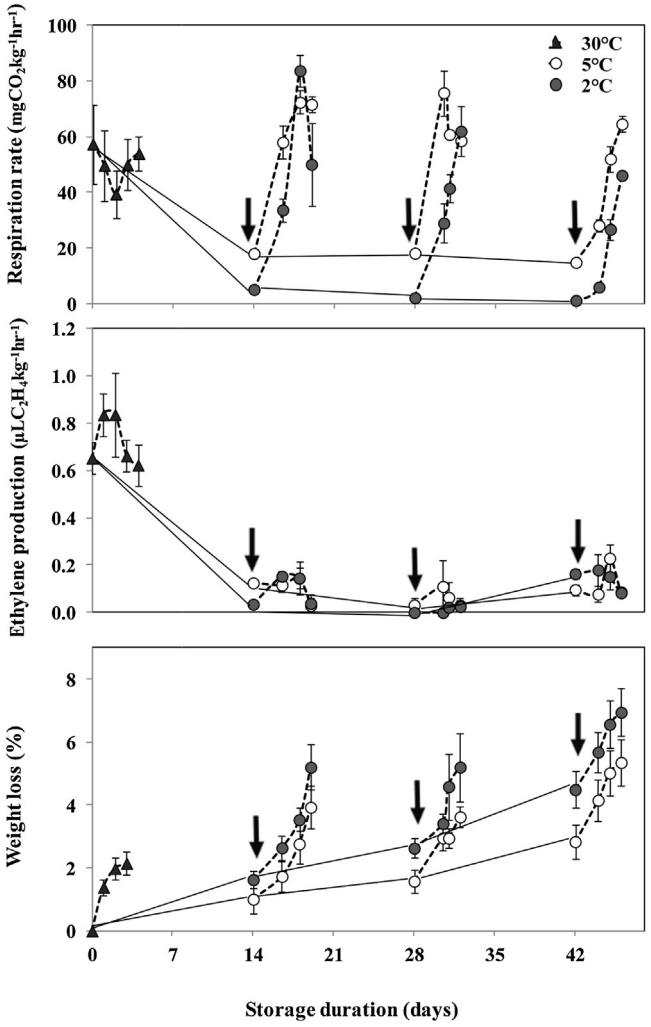

Fig. 2. *Effect of cold storage on respiration rate, ethylene production and weight loss in partially de-husked Makapuno coconut.* Control fruit (filled triangles) were stored at 30 °C then respiration, ethylene production and weight loss were measured for 3 days. Fruits were stored at 5 °C (open circles) and 2 °C (filled circles) for 14, 28 or 42 days and were then transferred to 30 °C (as indicated by the arrow) for an additional 3 days (dashed line). Values are mean ± SD of 6 fruits.

3.2. Effect of low temperature storage on Makapuno coconut quality

As the temperature used for storage decreased from 30 °C to 5 °C, the respiration rate declined 3-fold to 20 mg CO_2 kg^{-1} h^{-1} and ethylene production was reduced 6-fold to 0.1 μL C_2H_4 kg^{-1} h^{-1}. Lowering the storage temperature to 2 °C caused the respiration rate to further decline to 4 mg CO_2 kg^{-1} h^{-1}. Following transfer from 2 °C or 5 °C to 30 °C, the respiration rates rapidly increased. However, after 3 days upon transferring, the respiration rate of the 6-weeks stored fruits were not statistically significant difference from the fruit kept at 30 °C and ethylene production did not change (Fig. 2).

At 5 °C storage, weight loss remained at 3% in coconut held for 42 days. Upon transfer to 30 °C for 3 days, water loss increased rapidly but was still less than 6%. However, in Makapuno coconut stored at 2 °C for 42 days the proportion of water loss increased to 4.5% and was even higher after transfer to 30 °C for 3 days (Fig. 2).

The color of the meat after 6 weeks at 2 or 5 °C and 3 additional days at 30 °C was not different from fruit stored at 30 °C for 3 days ($P > 0.05$), however, the a^* value was higher (−0.86 to 0.43) in the former. The SS, TA, MDA and decay incidences of fruit stored at 5 °C

Table 1
The quality of Makapuno coconut after storage at 30, 5, and 2 °C followed by storage at 30 °C for 3 additional days. 'Kernel' and 'water' describe the outer endosperm and inner endosperm, respectively.

Storage condition	Kernel			Water		Kernel	Decay score[1]
	L^*	a^*	b^*	SS (°Brix)	TA (%)	MDA (nmol mL^{-1})	
At harvest	67bcd	−0.65cde	1.05f	5	0.03a	155a	1.0a
3d at 30 °C	66abcd	−0.86abc	−0.96cde	6	0.05ab	361ab	1.7ab
				5 °C			
2 w	67bcd	−0.97ab	−1.09bcde	7	0.08abc	475bc	1.0a
2 w + 3 d at 30 °C	61ab	−0.79bcd	−2.22ab	7	0.07abc	841ef	1.0a
4 w	70cd	−0.92abc	−1.09bcde	6	0.08abc	698cde	1.0a
4 w + 3 d at 30 °C	64abc	−0.52de	−1.61abcd	6	0.07abc	584bcd	1.0a
6 w	72d	−0.88abc	−0.64de	5	0.09abc	746def	1.0a
6 w + 3 d at 30 °C	59a	−0.43e	−0.90cde	6	0.09abc	466b	2.3abc
				2 °C			
2 w	67bcd	−0.92abc	−0.48de	6	0.07abc	365ab	1.0a
2 w + 3 d at 30 °C	63abc	−0.94abc	−2.50a	7	0.07abc	815ef	1.7ab
4 w	72d	−1.12a	−0.06e	7	0.05ab	925ef	1.7ab
4 w + 3 d at 30 °C	60a	−0.55de	−1.98abc	6	0.10cd	1026g	3.0bc
6 w	72d	−0.88abc	−0.64de	7	0.08abc	974fg	3.7cd
6 w + 3 d at 30 °C	59a	−0.43e	−0.90cde	7	0.11d	566bcd	5.0d
F-test	*	*	*	*ns*	*	*	*
% CV	8.6	33.2	105.2	16.7	35.9	42.8	78.5

Means followed by the same letter in each column are not significantly different and means followed by the different letters are significantly different at $P \leq 0.05$ according to Duncan's new multiple range test. Values are means of 6 replicates.

[1] Decay scores are made as described in Section 2.

remained the same as those stored at 30 °C for 3 days. In contrast, fruit stored at 2 °C were free of decay for only 4 weeks (Table 1).

3.3. Effect of modified atmospheric packaging using high oxygen transmission rate (OTR) plastic bag on Makapuno coconut quality

CO_2 and ethylene concentration inside the high OTR packaging increased from 0.06% to 0.69% and 0.05 to 0.12 ppm, respectively, while O_2 concentration was reduced from 21% to 15% ($P < 0.05$). The combination of storing fruit in a high OTR bag and holding them at 5 °C effectively suppressed the growth of microbes and reduced weight loss to 0.88% so that the fruit remained healthy and free of decay for up to 10 weeks. After transfer to 30 °C for 3 days, the overall quality including a^* values, SS, TA and MDA remained unchanged compared with the fruit at harvest although the L^* and b^* values decreased significantly ($P > 0.05$) (Table 2).

4. Discussion

The overall aim of this work was to determine the conditions necessary to extend the storage life of partially de-husked Makapuno coconuts after harvest. Our observation of Makapuno coconut maturation agreed with the findings of Islam et al. (2009). Makapuno coconut reached early maturation ~9 months after flowering (MAF) and became fully mature ~10–11 MAF. The endosperm is thicker and softer than that of normal coconut and the liquid endosperm filled the rest of cavity. Our data showed no significant difference in respiration and ethylene production of Makapuno coconut harvested between 9 and 11 MAF (Supplementary Fig. 1).

4.1. Changes in quality of Makapuno coconut after harvest and storage life

Since there are no published data on the postharvest biology of Makapuno that we are aware of, this work is the first evaluation of the compositional, physiological and biochemical changes in Makapuno coconut fruit after harvest. During 3 days of storage at 30 °C, the rates of respiration and ethylene production for Makapuno were similar to those reported for normal mature coconut genotypes (Paull and Ketsa, 2004). However, the respiration rate from disks of Makapuno coconut was found to be higher than that of intact whole fruit (Angela and Evelyn, 1993). This may be due to differences between whole fruit and disks in term of (1) the amount of surface area exposed to the atmosphere or (2) the gas transmission and gas solubility through the tissues.

Postharvest fruit quality can be partially assessed by evaluating SS, TA and weight loss. The SS of de-husked normal coconut declines but TA increases as the postharvest storage period increases (Ohler, 1984; Paull and Ketsa, 2004). Normal harvested mature coconuts lose weight gradually over the storage period due to water evaporation from the fruit cavity or due to absorption by the kernel (Copeland, 1931). In contrast, Makapuno coconut in this study exhibited less weight loss probably due to the viscosity of the endosperm, which restricted water loss through evaporation (Child, 1974; Menon and Pandalai, 1958; Veloso, 1983). Consequently, the color, SS and TA of Makapuno meat did not significantly change after 3 days of 30 °C storage.

One of the major problems with coconut storage is the increasing rancidity of the endosperm that results from lipid oxidation i.e. the oxidative deterioration of lipids. This leads to an undesirable taste and smell during storage. Malondialdehyde (MDA) is used as an indicator of lipid peroxidation (Cakmak and Horst, 1991), and generally, higher MDA levels correlate with higher rancidity (Pathirana et al., 2011). Although insignificant ($P > 0.05$), the MDA of the meat increased 2-fold after 3 days at 30 °C storage. Compared to other coconuts, lipid oxidation is less problematic for Makapuno during storage, probably due to the lower crude fat relative to non-Makapuno types (Adriano and Manahan, 1931; Santoso et al., 1996).

Another major problem of harvested coconut is decay. Deterioration of Makapuno fruit was evident as mold infestation on the husk surface, which also penetrated the fruit 'eye' after they were transferred to 30 °C for 3 days (data not shown). The most prevalent fungal molds found on Makapuno husks were *Aspergillus* spp. and *Penicillium* spp. but *Fusarium* spp. and *Curvulria* spp. were also detected (data not shown). Treating fruits with 3–5% (w/v) sodium metabisulfite ($Na_2S_2O_5$; SMS) or linear low-density polyethylene—file (LLDPE-film) wrap could not prevent surface mold or extend Makapuno coconut storage life when stored at 30 or 5 °C (Supplementary Table 1).

Table 2
Effect of high OTR bag on changes in gas composition and Makapuno coconut quality during storage at varying time–temperatures regimes.

Storage condition	CO_2 (%)	O_2 (%)	C_2H_4 (ppm)	Weight loss (%)	Kernel			Water		Kernel MDA (nmol mL^{-1})	Decay score
					L^*	a^*	b^*	SS (°Brix)	TA (%)		
At harvest	0.06a	21.0b	0.05a	–	67b	−0.65cd	1.05c	5.30	0.03ab	258ab	1.0
5 °C + LDPE packaging											
6 w	0.32b	14.7a	0.04a	0.55a	71bc	−1.26a	−1.00b	6.53	0.09d	354bc	1.0
6 w + 3 d at 30 °C	–	–	–	0.76bc	61a	−0.78bcd	−2.50a	7.33	0.09d	378c	1.0
8 w	0.40b	16.4a	0.11b	0.63ab	72c	−1.07ab	−0.63b	6.08	0.05bc	237a	1.0
8 w + 3 d at 30 °C	–	–	–	1.08d	62a	−0.70cd	−2.15a	6.33	0.07cd	270ab	1.0
10 w	0.69c	14.6a	0.12b	0.66ab	73c	−0.84bc	−0.18b	7.15	0.11e	206a	1.0
10 w + 3 d at 30 °C	–	–	–	0.88cd	58a	−0.43d	−2.15a	7.48	0.03ab	279ab	2.1
F-test	*	*	*	*	*	*	*	*ns*	*	*	*ns*
%CV	67.5	56.7	17.9	26.9	9.4	39.2	111	21.1	47.5	36.6	25.0

Means followed by the same letter in each column are not significantly different and means followed by the different letters are significantly different at $P \leq 0.05$ according to Duncan's new multiple range test. *F*-test values indicated with an asterisk are significant to $P \leq 0.05$. Values are means of 6 biological replicates.

4.2. Effect of low temperature on Makapuno coconut quality

As expected, fruit storage-life increased with decreasing temperature. At 5 °C the rate of respiration and ethylene production was reduced 3–6 fold and the storage life was increased to 42 days when stored at 5 °C rather than 3 days at 30 °C. Moreover, following transfer from 5 to 30 °C, respiration rates were similar to fruit kept continuously at 30 °C and ethylene production did not change (Fig. 2), indicating that there was little or no chilling injury using these temperatures and storage times (Luengwilai and Beckles, 2010). During the 6-week storage period, fruit weight loss was significant but endosperm color, SS, TA and decay incidence were similar to those that were stored at 30 °C for 3 days. This may indicate that most of weight loss caused by loss of moisture from husk but not from the endosperm.

Makapuno fruit developed symptoms consistent with postharvest chilling injury when stored at 2 °C for 4 weeks. Cold-stored fruits transferred to 30 °C for an additional 3 days exhibited signs of deterioration: the meat developed a woolly texture, and a rancid smell and taste coincided with higher MDA and decay scores. Thus, 2 °C was more unsuitable for Makapuno coconut storage than 5 °C.

4.3. Effect of storage temperature and high OTR bag on Makapuno coconut quality

Generally, enclosing fruit in films, bags or coatings reduces water loss, prevents the spread of disease among batches of stored fruit and establishes an atmospheric composition that slows down deterioration (Kader et al., 1989). It was previously reported that high-OTR bags can enhance the shelf life of mature coconuts (Puchakawimol, 2004). To determine the effect of high-OTR on Makapuno coconuts quality, fruits were stored individually in high-OTR bags and kept at 5 °C and compared to unbagged fruits held at 5 °C. Coconuts in high-OTR bags had a high O_2 transmission rate which allowed O_2 to escape from the bag resulting in low O_2 accumulation inside. Ethylene also accumulated, but the concentration was lower than 0.15 ppm. While the unbagged Makapuno coconut could be stored only for 6 weeks at 5 °C, Makapuno coconut kept in high-OTR bag and stored at 5 °C lasted for 10 weeks without any sign of deterioration. In addition, high OTR bag and 5 °C storage minimized evaporation very effectively as there was almost no weight loss after 10 weeks and there was no change even after transfer to 30 °C for 3 additional days (Table 2). This reduction in weight loss is likely due to the high relative humidity maintained inside the bag.

The combination of high-OTR bag and 5 °C effectively suppressed the growth of microbes probably via protecting the coconut from direct contact with fungi and preventing moisture condensation on husk surface. The CO_2 and O_2 concentration were not high or low enough to kill the fungi therefore it is unlikely that the modified atmosphere would affect fungi pathogen metabolism. The MA provided by the high-OTR bag also maintained SS, TA and MDA levels even after transfer to 30 °C. After 10 weeks storage in high OTR bags, fruit quality was maintained and coincided with a reduction in water loss. Thus it is hypothesized that the reduction in water loss might be the most important factor prolonging Makapuno storage life when stored in high OTR bags. However, conclusive proof of this hypothesis requires further experiment.

5. Conclusion

Low temperatures increased the storage-life of Makapuno coconut from 3 days at 30 °C, to 6-weeks at 5 °C. Shelf-life and the visual and compositional quality of Makapuno coconuts were best maintained in fruit kept in high OTR bags and stored at 5 °C. High-OTR bags reduced pathogen infestation, weight loss, rancidity and allowed storage of coconut fruits for up to 10 weeks. High OTR bags and low temperature storage (minimum 5 °C) are therefore recommended for maximal storage life of Makapuno coconuts.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.scienta.2014.06.005.

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