International Food Research Journal 22(1): 178-189 (2015)
Journal homepage: *http://www.ifrj.upm.edu.my*

Response of gac fruit *(Momordica cochinchinensis* Spreng) to postharvest treatments with storage temperature and 1-MCP

[1]Soe Win, [1,2]Buanong, M., [1,2]Kanlayanarat, S. and [1,2,*] Wongs-Aree, C.

[1] *Postharvest Technology Program, School of Bioresources and Technology, King Mongkut's University of Technology Thonburi, Bangkok 10140, Thailand*
[2] *Postharvest Technology Innovation Center, Commission on Higher Education,Bangkok 10400, Thailand*

Article history

Received: 9 June 2014
Received in revised form: 22 July 2014
Accepted: 24 July 2014

Keywords

Momordica cochinchinensis
Spreng
Phenolics
Antioxidant activity
Storage temperature
1-MCP

Abstract

The effects of various low temperatures and 1-methylcyclopropene (1-MCP) pre-treatments on changes in physical, physiological, and phytochemical attributes, and in antioxidant activity of gac fruit were evaluated during storage. Low temperature regimes, including 4, 10, and 13ºC had the greatest impacts on ripening, color changes, and bioactive compound content of gac fruit, compared to control at 25ºC. However, fruit stored at 4ºC showed both external and internal chilling injury symptoms starting from day 25 of the storage. Low temperature greatly preserved the reduction of phenolics and antioxidant capacity detected by FRAP (Ferric Reducing Antioxidant Power) during storage. 1-MCP fumigation at 500 nL·L^{-1} showed slight effect on retarding an increase of ethylene production and on delaying fruit softening during 10ºC storage. Nevertheless 1-MCP had no effect on changes of peel color, phytochemicals and antioxidant activity of gac fruit.

Introduction

Gac (*Momordica cochinchinensis* Spreng), one of the family members of Cucurbitaceae, is an indigenous plant to Southeast Asia and a popular fruit in Vietnam (Vuong *et al*., 2006). It has recently emerged as a prominent vegetable fruit for health, showing colorful fruit with high content of antioxidants and nutritional value. Whereas in Vietnam the bright red seed pulp (aril) of the ripe fruit is primarily used in the preparation of *"xoi gac"* (red rice) (Vuong, 2000), the fruit is consumed for different purposes at different developmental stages in Thailand. Immature gac fruit (green) is consumed as vegetable while the fruit meat (pulp) which has a flavor similar to papaya and is cooked or boiled, is consumed with chili paste or used in a curry. The aril of ripe gac is used as raw material for juice or ice cream processing (Kubola and Siriamornpun, 2011). Furthermore, gac pulp and aril are not only consumed for dietary purposes, but for medicinal functions (Iwamoto *et al*., 1985; Vuong *et al*., 2006). The fruit can make significant contributions of disease prevention, particularly by reducing vitamin A deficiency. Vuong *et al*. (2002) found that daily consumption of *"xoi gac"* significantly improved plasma levels of retinol, α- and β-carotenes, and lycopene in pre-school children. As rich sources of phytochemicals such as carotenoids, phenolics, and antioxidants, foods made from gac fruit play a role in cancer prevention by scavenging reactive oxygen species and preventing intracellular damage (Nunes *et al*., 2012).

For local use for processing as a food and other products, the gac fruit growers normally harvest the fruit at full ripening stage (red color peel) which has only 7 days of shelf life at ambient conditions (Soe Win *et al*., 2015). The previous study on changes in postharvest quality and bioactive compounds of gac fruit at different maturity stages showed that the yellow stage of gac fruit was suitable for long term storage, while fully ripened fruit had a range of physiological changes and produced high respiration rate of 102.42 mg CO_2·kg^{-1} h^{-1} and ethylene production rate of 1.04 µL·kg^{-1} h^{-1} (Soe Win *et al*., 2015). There is currently a high demand from both domestic and export markets for fresh fruit for consumption but little information is available about postharvest and storage techniques. Its short postharvest life, high susceptibility to mechanical damage and pathogens limit the distribution to domestic markets. The rapid softening of fruit leads to losses in the supply chain due to bruising and over-ripeness. Therefore, development of postharvest handling techniques aiming at regulating ripening and curtail losses from postharvest disorders and diseases is crucial to

*Corresponding author.
Email: *chalermchai.won@kmutt.ac.th*

increase commercialization of gac fruit.

Long term storage management almost exclusively involves the management of temperature and gas composition in the storage room (controlled atmosphere storage) and coating with edible materials (Kader, 1995). Storage temperature is one of the most important factors affecting the quality and maintenance of the shelf-life of fresh produce (Roura *et al.*, 2000). The lower storage temperature is, the longer storage life extension of fresh produce by reducing respiration rate and senescence will be, accompanied by a reduction of growth of spoilage microorganisms (Watada *et al*., 1996; Roura *et al*., 2000), in spite of a limitation due to a minimum temperature required by tropical fruits. Every fresh produce has an optimum storage temperature depending on geographic origin of the products. Although low temperature has been widely used to store fruits and vegetables given the beneficial effects of low temperature in delaying senescence and maintaining quality, there is little information regarding the antioxidant activity of different parts of gac fruit, and no information concerning the changes of phytochemicals and antioxidant activity of gac fruit during low temperature storage. Besides the storage temperature, 1-MCP has been successfully used in extending shelf-life and maintaining quality of fruits and vegetables. The use of 1-MCP is increasing in postharvest storage to extend the commercial life of fruits and vegetables. 1-MCP is now registered in many countries, though its first commercial applications date back only a few years (Blankenship and Dole, 2003). 1-MCP has a non-toxic mode of action, leaves negligible residues and is active at very low concentrations (Watkins, 2006). The action mechanism of 1-MCP involves competition with ethylene receptors for the binding site (Sisler and Serek, 1997), and it usually affects respiration rate and weight loss, and the onset of ethylene-dependent quality traits and perception (Dal Cin *et al*., 2006; Watkins, 2006). The successful application of 1-MCP to whole fruit is strongly dependent on many factors, among them the species, cultivar and harvest maturity stage, the concentration applied, exposure time, temperature and frequency of application (single or cyclic), its application alone or in combination with other gases, and the subsequent postharvest conditions of temperature, relative humidity (RH), atmosphere, and storage duration (Watkins, 2006; Sozzi and Beaudry, 2007). Therefore, this experiment was conducted to select the optimum storage temperature combined with 1-MCP to maintain quality, extend the shelf-life and investigate the changes of phytochemicals and antioxidant activity of gac fruit.

Materials and Methods

Material preparation

Gac fruit at the yellow peel maturity stage (40 days after fruit setting) were harvested from 3 years-old plants at a commercial orchard in Nakorn-Pathom province, Thailand (latitude: 14º 01’ 16.08” N; longitude: 99º 58’ 53.63” E) between March and August 2013. The average day and night temperatures, and annual rainfall during the study time were 29ºC, 26ºC and 1490 $mm \cdot y^{-1,}$ respectively. The fruit were transported to the Postharvest Technology laboratory at King Mongkut’s University of Technology Thonburi, Bangkok within 2 h after harvest. After arrival, fruit were washed and dipped in 200 $mg \cdot L^{-1}$ sodium hypochlorite and then 500 $mg \cdot L^{-1}$ imidazole. Fruit were dried at room temperature and selected for uniformity of size (about 500 to 600 g per fruit) and color.

Experimental design

Gac fruit harvested in March 2013 were randomly divided into four groups and stored at different temperature regimes of 4, 10, 13ºC (90 – 95% RH) or 25ºC (65 – 70% RH) for a month. In each storage temperature, four replications were assigned to a completely randomized design (CRD) in which two fruit for each replication were sampled. During storage, samples were taken at 5-days interval to measure the changes of physical (weight loss percentage, firmness, and color changes), physiological (respiration rate and ethylene production), and phytochemical characters (total phenolics contents, and antioxidant activity).

For a subsequent experiment of 1-MCP treatment, fruit harvested in August 2013 were pretreated by fumigated with 0 (control), 500, and 1000 $nL \cdot L^{-1}$ 1-MCP (AnsiP-G, Taipei and Taiwan or EthylBlocTM Sachet) in a 43-L glass chamber at 25ºC for 12 h. The experiment was designed as a CRD with four replications (one fruit per replication). After treatments, the fruit were ventilated to remove residual 1-MCP and transferred to the 10ºC (90 – 95% RH) storage room. The same parameters measured in storage temperature experiment were analyzed at 5-days interval.

Measurement of weight loss and fruit firmness

The fresh weight of gac fruit was determined after treatment and weight loss was calculated as a percentage of the initial weight. Firmness of whole

fruit was measured in the middle on two opposite sides of each fruit using a texture analyzer (TA-XT2, Stable Micro Systems Ltd., UK) with a 5-mm diameter plunger and a constant moving rate of 10 mm·min^{-1} for a 10 mm depth. The mean values for maximum force were reported in Newtons (N).

Fruit color changes

Peel color was measured from the middle of the gac fruit in three different places of each fruit by a colorimeter (Model RC-300, Minolta Co. Ltd., Osaka, Japan). Colors were collected as lightness (L^*), green and red (a^*), and blue and yellow (b^*). Numerical values of a^* and b^* were calculated into hue angles ($H^o = \tan{-1}\ b^*/a^*$) (Francis, 1980). A change in hue indicates fruit ripening from green to yellow or red, where 0 = red, 90 = yellow, and 180 = green. The color change (ΔE = a metric of the difference or distance between two colors) was computed by using the following formula:

$$\Delta E = \sqrt{(L_0^* - L^*)^2 + (a_0^* - a^*)^2 + (b_0^* - b^*)^2}$$

where, L_0^*, a_0^* and b_0^* = color values of samples on initial day of the experiment, and L^*, a^* and b^* = the color values of samples at 5 days interval.

Measurement of respiration rate and ethylene evolution

Gac fruit was kept in an airtight container (1.8 L) for 1 – 2 h (closed system) under indicated storage temperature regimes to monitor the respiration rate and ethylene (C_2H_4) concentration. One mL gas sample was withdrawn from the headspace of the chamber using a one mL plastic syringe with a 1-inch (2.54 cm) long needle. Carbon dioxide production was determined by gas chromatography using Shimadzu Model 8A (Kyoto, Japan) equipped with a stainless steel column packed with Porapak Q 80/100 mesh (set to 80ºC) and a thermal conductivity detector. Helium was used as carrier gas at a flow rate of 30 mL·min^{-1}. Ethylene production was measured by gas chromatography using Shimadzu Model 14B (Kyoto, Japan) equipped with a 60/80 mesh Propak Q column (set to 80ºC) and a flame ionization detector (FID), and nitrogen was used for the carrier gas at a flow rate of 35 mL·min^{-1} equipped with a stainless steel column packed with Porapak Q 80/100 mesh and a flame ionized detector. Helium was used as carrier gas.

Extraction and determination of total phenolisc content and antioxidant activity

The freeze-dried samples of peel, pulp and aril from gac fruit were extracted using the method modified from Abu Bakar *et al*. (2009). The samples prepared from the frozen fruit (1 g) were extracted for 2 h with 10 mL of 80% methanol at room temperature on an orbital shaker set at 180 rpm. The mixture was centrifuged at 1400 g for 20 min and the supernatant was decanted into a 30 mL vial. The pellet was re-extracted under identical conditions. The supernatant was combined and used for the total antioxidant activity and total phenolics content.

Total phenolics content in the extracts was determined spectrophotometrically according to the Folin–Ciocalteu method (Abu Bakar *et al*., 2009). Briefly, 300 µL of extract were mixed with 2.25 mL of Folin–Ciocalteu reagent diluted (1:10) in distilled water and allowed to stand at room temperature for 5 min; 2.25 mL of sodium carbonate (60 g·L-1) solution was added to the mixture. After 90 min at room temperature, the absorbance was measured at 725 nm using a spectrophotometer. The total phenolics content of the extracts was calculated and expressed as gallic acid equivalents per 100 gram of fresh weight (mg GAE·100 g^{-1} FW) based on the gallic acid standard curve.

The principle of Ferric Reducing Antioxidant Power (FRAP) method is based on the reduction of a ferric-tripyridyltriazine complex to its ferrous, colored form in the presence of antioxidants. The total reducing capacity was determined using the FRAP assay (Benzie and Strain, 1996). The FRAP reagent contained 25 mL of a 10 mmol·L^{-1} TPTZ (2,4,6- tripyridy-s-triazine, Sigma) solution in 40 mmol·L^{-1} HCl plus 25 mL of 20 mmol·L^{-1} $FeCl_3$ and 250 mL of 0.3 mol·L^{-1} acetate buffer, pH 3.6 and the fresh working solution was prepared and heated to 37ºC before using. The 150 µL of fruit extracts were allowed to react with 2850 µL of the fresh working FRAP solution. After incubation for 30 min, the absorbance was read at 593 nm using a spectrophotometer. A standard curve was prepared by plotting the percentage (%) of free radical scavenging activity of Trolox versus its concentration.

Statistical analysis

The experiments were conducted following a completely randomized design (CRD). Data were analyzed using ANOVA in SPSS program (Version 11.0) and difference among means was compared using the least significant difference (LSD) test at $P \leq 0.05$.

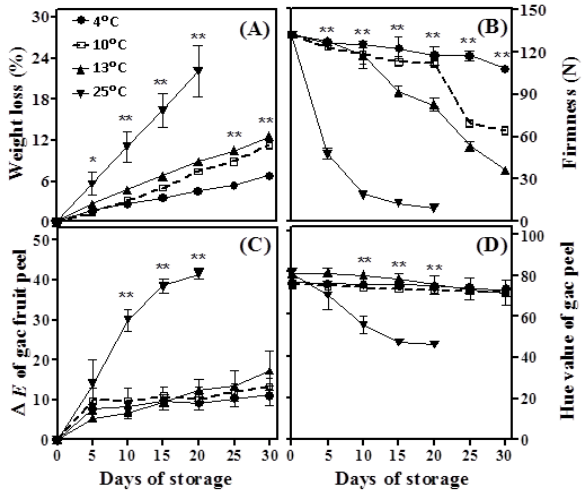

Figure 1. Effect of different storage temperatures on weight loss (A), firmness (B), color changes (ΔE values) (C) and hue value (D) of gac fruit. Data represent means ± SE of four replications

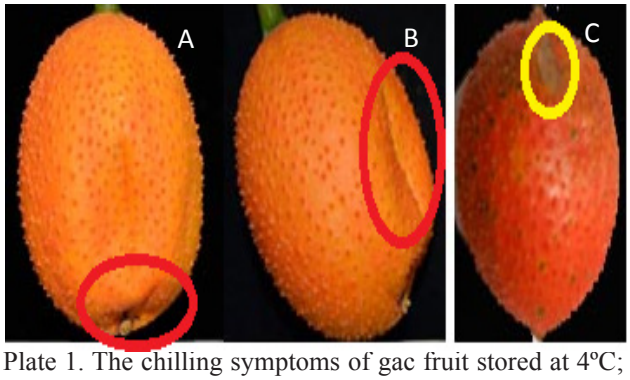

Plate 1. The chilling symptoms of gac fruit stored at 4ºC; the shriveling of fruit (A and B) and water soked area on the peel of fruit (C)

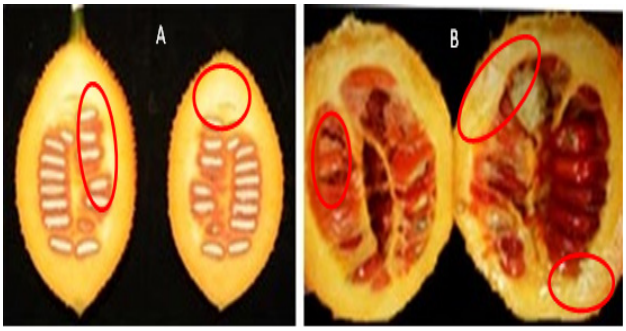

Plate 2. The internal disoders of gac stored at 4ºC; the abnormal ripening of mesocarp and aril (A) and the water leathery like mesocarp and abnormal aril (B)

Results and Discussion

Effects of low temperature on physical changes and disorders of gac fruit

The weight loss percentage of gac fruit was significantly affected by storage temperature. Its weight change was positively related to the storage temperature, and weight loss of gac fruit increased with storage time which was more prominent at 25ºC (Figure 1A). The highest weight loss percentage was observed in gac fruit stored at 25ºC, when about 22.03% of its initial weight was lost on 20th day of storage (DOS). Fruit stored at 25 ºC and low relative humidity of 65-70% showed slight peel shriveling on day 15 and were mostly infected by fungus and then rotted after 20 DOS. Due to this infection, the weight loss percentage of gac stored at 25ºC increased more rapidly than in other treatments. Fruit held at 4ºC had the lowest weight loss (only 6.77% of their initial weight) followed by fruit held at 10 and 13ºC (11.19% and 12.50%, respectively) at 30th DOS. Although the fruit stored at 4ºC had the lowest weight loss percentage, some abnormal features of chilling injury were observed at the end of storage. Postharvest weight loss in fruit is usually due to the loss of water through transpiration. Water loss during storage is a major cause of fruit deterioration. Reduction in turgidity as a result of water loss causes shriveling and faster depletion of nutrients. Weight loss can lead to shriveling which reduces both the market value and consumer acceptability. De Castro *et al.* (2006), who tested the effects of different storage temperatures in tomato, demonstrated that weight loss was proportional to the storage period and storage temperature. High temperature increases the rates of respiration and other metabolic processes that cause depletion of substrates like sugars and proteins resulting in further weight loss (Nyanjage *et al.*, 2005). At higher temperatures, vapor pressure deficit increases, resulting in increased water loss which mainly accounts for weight loss. Lower weight loss that coincided with a decrease in storage temperature is in agreement with the findings of Ramana Rao *et al.* (2011).

Fruit firmness is the main important character of gac subjected to mechanical damage during transportation and storage. The decrease in fruit firmness is an indication of the level of softening of fruit. The firmness of gac fruit kept at 25ºC on 5th DOS declined more rapidly than that of fruit stored at 4, 10, and 13ºC, which coincided with the rise in respiration and ethylene production. The firmness of gac stored at 25ºC suddenly decreased from 132.8 N to 19.57N within 10 DOS, whereas that of the fruit stored at 4, 10, and 13ºC decreased gradually. The lowest decrease in firmness was observed in fruit stored at 4ºC (Figure 1B). During ripening, the fruit tended to soften either as result of the cells losing water and becoming less turgid or by the breakdown of the cell walls as a result of increasing metabolism (Kashmire and Kader, 1978). Loss of fruit firmness in fruit was due to the softening of the cell wall, which may be due to the activity of softening enzymes

Table 1. Effect of different storage temperatures on mean of total phenolics content in peel, pulp and aril of gac fruit

Treatments	Total Phenolics Content (mg GAE·100^{-1} g FW) [1/]						
	Peel						
	D0	D5	D10	D15	D20	D25	D30
4ºC	266.50	154.83a	136.83ab	113.50	105.83a	101.83ab	95.50
10ºC	266.50	156.83a	148.17a	114.17	109.83a	103.17a	86.17
13ºC	266.50	147.83b	102.17bc	84.83	78.83b	85.17b	81.50
25ºC	266.50	113.50b	69.83c	76.17	68.50c	-	-
F-test	1	*	*	ns	**	*	ns
CV%	13.67	16.74	19.77	35.12	10.62	11.39	16.35
	Pulp						
4ºC	55.17	52.17b	100.83a	56.50b	60.83	194.50a	166.50a
10ºC	55.17	67.50a	71.17ab	85.83a	68.17	129.17b	123.50b
13ºC	55.17	60.17b	56.17b	48.17b	61.17	143.83b	111.83c
25ºC	55.17	70.83a	54.50b	49.50b	47.17	-	-
F-test	ns	*	*	*	ns	**	**
CV%	30.13	23.64	29.06	24.61	28.36	8.8	2.63
	Aril						
4ºC	276.83	174.17	102.50c	109.50a	106.83b	98.17	94.17ab
10ºC	276.83	179.83	148.83a	116.83a	100.17a	96.50	122.17a
13ºC	276.83	182.83	98.83ab	93.50b	97.50b	92.17	74.83b
25ºC	276.83	149.50	78.17c	53.83b	58.50c	-	-
F-test	ns	ns	**	**	**	ns	*
CV%	12.73	12.76	21.79	43.47	18.71	21.52	15.96

[1/] Means (n=4) with different lower case letters within the same column are significantly different.
ns: non significant, * Significant difference at $P \leq 0.05$, ** Significant difference at $P \leq 0.01$

(Chuni *et al*., 2010). Low temperature treatment was an effective way to maintain fruit firmness and to delay fruit softening, resulting in extending the storage life of fruit.

The natural color of gac peel change from yellow to red. The color changes of gac fruit peel were affected by the storage temperature and the changes increased as the storage time progressed. Among temperature treatments, 25ºC storage hastened the color changes of gac peel. The color changes of gac stored at 4, 10, and 13ºC were not significantly different during storage (Figure 1C). Fruit stored at 25ºC turned from yellow to red in 10 days and the decrease of peel hue value was very pronounced whereas there was only a slight change of hue value of gac fruit peel stored at 4, 10, and 13ºC (Figure 1D). The color change in fruit was due to a decrease in chlorophyll and an increase in carotenoid synthesis reflecting the transformation of chloroplasts to chromoplasts (Pretel *et al*., 1995). The low temperatures would retard the carotenoid biosynthesis since fruit stored at 4, 10, and 13ºC just turned orange at the end of storage.

Although low temperature may prolong storage life, excessively low temperature can cause chilling injury and result in loss of quality and shelf-life. On 25th DOS, we found that the fruit stored at 4ºC showed several external chilling injury symptoms including improper ripening and shriveling (Plate 1A), tissue collapse (Plate 1B) and water soaked area

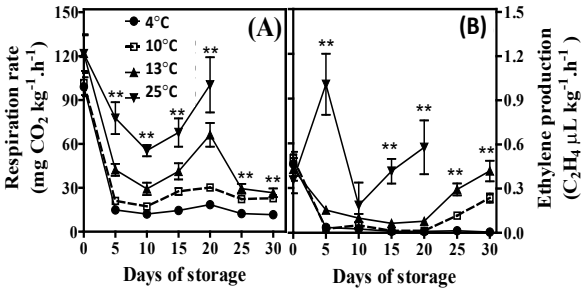

Figure 2. Effect of different storage temperatures on respiration rate (A) and ethylene production (B) of gac fruit. Data represent means ± SE of four replications

was found on the peel (Plate 1C). Moreover, when the internal pulp and aril were examined, the aril was not showing its normal color i.e. it was pale red (Plate 2A) and the pulp (mesocarp) showed leathery like meat (Plate 2B) that was not edible.

Effect of low temperature on physiological characters

The respiration rates of gac fruit decreased on 10th DOS and increased on 20th DOS (Figure 2A). Among three storage temperature regimes, the fruit stored at 4ºC showed the lowest respiration rate while the highest one was observed in those stored at 25ºC, due to the fungal infection on 20th DOS. The same results were reported by Bhande *et al*. (2008) in bananas and Ding *et al*. (1998) in loquat fruit. On the 1st day after storage, a high rate of respiration was found that was due to abiotic stress such as transportation shock and mechanical injury during

Table 2. Effect of different storage temperatures on mean value of antioxidant activity (measured by FRAP assays) in different fractions (peel, pulp and aerial) of gac fruit

Treatments	Antioxidant activity (TEA mg·100g^{-1} FW)$^{1/}$						
	Peel						
	D0	D5	D10	D15	D20	D25	D30
4ºC	380.83	347.00b	428.83b	333.00b	283.67ab	240.50	237.67a
10ºC	380.83	367.33a	560.33a	399.33a	415.83a	240.00	257.50a
13ºC	380.83	487.17b	335.17c	266.00c	318.33ab	282.83	121.33b
25ºC	380.83	365.50b	239.83d	323.83bc	189.83b	-	-
F-test	ns	**	**	**	**	ns	**
CV%	16.93	9.02	9.21	9.99	24.76	11.23	16.77
	Pulp						
4ºC	181.50	149.00	151.33a	170.83b	160.83a	85.00a	78.83a
10ºC	181.50	158.67	168.17a	200.50a	178.83a	71.00a	63.17a
13ºC	181.50	151.00	138.00b	259.00a	184.83a	44.00b	34.17b
25ºC	181.50	145.17	121.83b	135.67b	106.00b	-	-
F-test	ns	ns	**	**	**	**	**
CV%	69.8	28.98	21.18	17.63	17.61	24.91	24.91
	Aril						
4ºC	265.00	236.33	427.50	404.33	329.33	307.17a	105.83
10ºC	265.00	250.83	427.50	350.83	327.33	272.00ab	128.50
13ºC	265.00	242.00	393.00	323.17	311.17	265.50b	127.00
25ºC	265.00	230.00	399.50	248.83	251.67	-	-
F-test	ns	ns	ns	ns	ns	**	ns
CV%	24.58	51.86	11.78	31.91	26.8	17.14	15.43

$^{1/}$ Means (n=4) with different lower case letters within the same column are significantly different.
ns: non significant, * Significant difference at $P \leq 0.05$, ** Significant difference at $P \leq 0.01$

transport. The diminution of enzymatic activities occurring at in general low temperature reduces the rate of respiration. Thus, fruit at low temperatures had lower rates of respiration than those kept at high temperature. The ethylene production of gac fruit stored at 25ºC suddenly increased on 5th DOS, decreased thereafter and then increased again. At 4, 10, and 13ºC storage temperatures, the ethylene production of gac gradually decreased till 20 DOS, and thereafter, the level increased in fruit kept at 13ºC (Figure 2B). The peak of ethylene production in gac coincided with the time of ripening, indicating that gac could be classified as a climacteric fruit. Biale *et al.* (1954) reported the findings on the role of ethylene in ripening fruits on the basis on measurements of ethylene produced by the fruit. However, the measurements were not sufficiently sensitive at threshold concentrations needed for physiological activity. After storage of gac at 25ºC, the increase of ethylene production might be explained by biotic stress such as fungal attacks. The ethylene production of gac kept at 4ºC showed no peak during the storage.

Effect of low temperature on phenolics content and antioxidant activity

The contents of phytochemicals in different fractions of gac fruit may be changed by many postharvest factors. Although gac aril of ripen fruit is mainly processed for juice and the pulp is used to cook a curry or food, the peel which is rarely used for consuming was measured in the present study to accumulate high amount of phenolics and antioxidant capacity. Nowadays, many different kinds of products such as soap, shampoo, even cosmetics are made from not only aril and pulp of gac but also from the peel. In general, total phenolics content in peel and aril of gac was gradually decreasing during storage while the phenolic contents in pulp increased when the fruit ripen. Among the three parts of fruit (peel, pulp, and aril) the highest contents of total phenolics was found in aril (276.83 mg GAE·100^{-1} g FW) followed by peel (266.50 mg GAE·100^{-1} g FW), and pulp (55.17 mg GAE·100^{-1} g FW) on the first day of storage (Table 1). Total phenolics content is associated with cultivar, pre- and postharvest handling factors. The storage temperature affected the loss of pheolics content in different fractions of fruit. The high temperature decreased the phenolics content and the highest value of phenolics content was observed in fruit stored at 10ºC at the end of storage. Gajewski *et al.* (2009) reported on eggplants stateing that the total phenolics content in fruit skin increased during storage, but the content in fruit flesh was not affected. Storage at 25ºC caused the highest reduction of phenolics content for almost all storage periods. Similar results were obtained by Rivera-Pastrana *et al*. (2010) in 'Maradol' papaya in which phenolics of 'Maradol' papaya were influenced by postharvest storage temperature and tended to decrease during ripening at 25ºC. However, the result

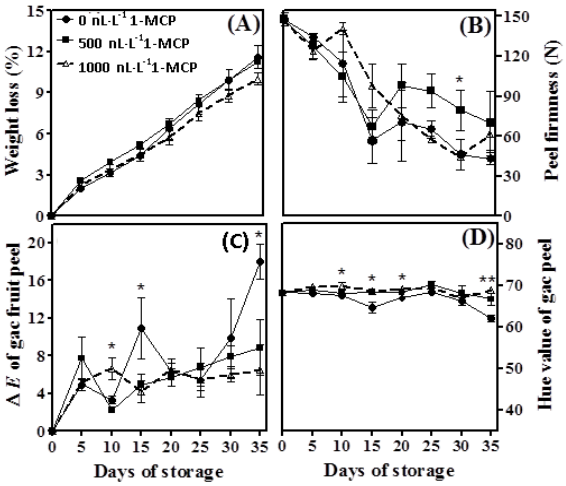

Figure 3. Effect of different dosages of 1-MCP on weight loss (A), firmness (B) color changes (ΔE value) (C) and hue value (D) of gac fruit storage at 10ºC. Data represent means ± SE of four replications

of the present study was opposite to that reported by Ayala-Zavala *et al*. (2004) in strawberries. They found that total phenolics content increased continuously in berries stored at 10ºC and 5ºC during storage time. In the present study at the lowest temperature (4ºC and 10ºC) the total phenolics content remained unchanged. This result agrees with the finidings of Tomas-Barberan and Espin (2001) who reported that phenylalanine ammonia lyase (PAL) activity was higher at lower temperatures. At the same time, the activity of enzymes responsible for polyphenol degradation, polyphenoloxidase, are inhibited by lower temperatures. Leja *et al*. (2003) stated that an increase in phenol content could be due to lower activity of polyphenoloxidase at low temperatures, so that oxidation processes were minimised. Increases in polyphenol content during shelf life can be explained by a higher ethylene production which results in a stimulation of PAL (Napolitano *et al.,* 2004).

Total antioxidant activities of gac fruit were measured with FRAP assay. Among the three fractions of gac the highest antioxidant activity was observed in peel (380.83 TEA mg·100g^{-1} FW) followed by aril (265.00 TEA mg·100g^{-1} FW), and the pulp (181.50 TEA mg·100g^{-1} FW) on the first day of storage (Table 2). The magnitudes of antioxidant activity measured by FRAP in gac peel was nearly constant during the storage and the high temperature decreased the antioxidant activity. Among the three parts of fruit (peel, pulp, and aril), the pulp had the lowest antioxidant activity and its values were affected by storage temperatures. Fruit antioxidants protect tissues against stresses and disease. Pinelo *et al.* (2004) reported that several food components, i.e. carotenoids, vitamin C, vitamin E, phenolic compounds and their interactions contribute to the overall antioxidant activity of foods, and thus, it is difficult to measure total antioxidant activity on the basis of individual active components. In general, the highest values of anitoxidant activity in pulp were found in fruit kept at low temperature. In aril the antioxidant activity decreased on 5th DOS and then increased till 25 DOS. The antioxidant activity in aril did not significantly differ between treatments except at 25ºC. The highest amount of antioxidant activity was observed in fruit stored at 4ºC followed by that of 10ºC. Overall, the fruit stored at low temperature maintained its the high antioxidant activity than those in high temperature. The decrease in the antioxidant activity may be due to the decreasing content of phenolic compounds in storage at high temperature. Similar result was found in blood orange (*Citrus sinensis* cv. Tarocco) by Hamedani *et al.* (2012) who reported that an increase in temperature and storage time reduced reduced the antioxidant capacity.

Among different storage temperature, 10ºC was an optimum storage temperature for gac fruit. Gac fruit stored at 10ºC had longer shelf life about 30 days without chilling injury symptoms while the shelf life of fruit at room temperature was about 15 days. Moreover, the fruit stored at 10ºC showed lower weight loss and maintained the fruit quality, in particular high fruit firmness, which is an important factor for transporatation and logistics. Althought the fruit stored at 4ºC had the highest total phenolics content and antioxidant activity, it could not ripen normally.

Effects of 1-MCP on physical responses of gac fruit

In previous study, the gac fruit showed an increase of ethylene production during ripening and thus, the gac fruit were treated with 1-MCP (0, 500, and 1000 nL·L^{-1}). There was no significant difference between treatments with regard to weight loss or fruit firmness (Figure 3A and B). There was a gradual weight loss increase and firmness decrease during the storage time and the 1000 nL·L^{-1} 1-MCP caused the lowest weight loss of fruit. The similar findings of no effect of 1-MCP on weight loss of oranges and tomatoes were stated by Porat *et al*. (1999) and Wills and Ku (2002), respectively. Jeong *et al.* (2003) stated that 1-MCP delay the weight loss in avocado. Massolo *et al.* (2011) reported that weight loss in eggplant treated with 1-MCP was significantly lower than control fruit because water exchange in eggplant occurred mostly through the calyx, and it is possible to associate the decrease in softening, weight loss and dehydration with the maintenance of

Table 3. Effect of different dosages of 1-MCP on changes in total phenolics content in different fractions (peel, pulp, and aril) of gac fruit stored at 10ºC

Treatments	Total phenolics content (mg GAE·100^{-1} g FW)$^{1/}$				
	Peel				
	D0	**D5**	**D15**	**D25**	**D35**
0 nL·L^{-1} (control)	275.75	277.92	264.08	241.92	233.42
500 nL·L^{-1}	275.75	256.25	241.42	237.75	235.92
1000 nL·L^{-1}	275.75	251.92	247.58	245.42	237.42
F-test	ns	ns	ns	ns	ns
CV%	3.77	9.15	5.52	3.06	1.85
	Pulp				
0 nL·L^{-1} (control)	61.83	66.50	48.50	41.833a	23.92
500 nL·L^{-1}	61.83	47.17	41.83	20.83b	20.92
1000 nL·L^{-1}	61.83	65.17	36.17	17.83b	16.08
F-test	ns	ns	ns	*	ns
CV%	43.77	38.97	12.31	41.96	30.94
	Aril				
0 nL·L^{-1} (control)	298.75	313.92	299.25	297.58a	231.25a
500 nL·L^{-1}	298.75	327.95	282.25	288.58b	238.25a
1000 nL·L^{-1}	298.75	304.08	276.92	279.75a	218.92b
F-test	ns	ns	ns	**	**
CV%	9.06	10.81	6.85	3.59	1.78

$^{1/}$ Means (n=4) with different lower case letters within the same column are significantly different.
ns: non significant, * Significant difference at $P \leq 0.05$, ** Significant difference at $P \leq 0.01$

calyx integrity in 1-MCP treated fruit, which might then result in higher resistance to water vapor flux. Weight loss of produce is mainly due to transpiration and evaporation of water inside the produces through surface. Moreover, cell wall degradation may affect water loss from produce, membrane permeability, and electrolytic leakage also participate in water loss from inside. Blankenship and Dole (2003) reported that the effective concentrations of 1-MCP vary with respect to species, cultivars, treatment time, and temperature.

The firmness of fruit treated by 1-MCP was not significantly different during the storage except on 30th DOS in which the highest firmness was found in 500 nL·L^{-1} 1-MCP treated fruit. Fan *et al*. (1999) and Vilaplana and Valentines (2006) studied apples in which 1-MCP delays the ripening-related changes that influence quality and especially reduces loss of firmness. In the present study on gac fruit, the lack of effect of 1-MCP on weight loss and firmness was due to low dosages and short duration of treatment. A similar result was obtained by Gutierrez *et al.* (2008) in goldenberry fruit in which treatment with 5 µL·L^{-1} 1-MCP tended to delay goldenberry softening at all stages though differences with control fruit were not significant, probably due to a relatively high variability. Tassoni *et al.* (2006) found that application of 5 µL·L^{-1} 1-MCP brought about little effect on firmness in tomato and another solanaceous species. Further studies are needed to determine if concentrations higher than those tested in this experiment will maintain firmness.

The gac fruit was harvested at the yellow stage and its peel color changed to red when ripe. The change of peel color (shown as ΔE value) was gradually increased during storage in all treatments (Figure 3C). No significant difference in peel color changes between treatments was observed in gac fruit during storage except on 10th and 35th DOS. At the end of storage (35 DOS), the highest peel color change was observed in control fruit and the lowest was obtained from 1000 nL·L^{-1} 1-MCP treated fruit. The hue values of gac peel treated with 1-MCP are shown in Figure 3D. Its values gradually decreased during storage, however, there was no significant difference between treatments during storage except on 10th, 15th, and 20th DOS. On those days the lowest hue value was observed in 500 nL·L^{-1} 1-MCP treated fruit. Gutierrez *et al.* (2008) stated that the hue angle was higher in 1-MCP-treated goldenberries fruit than in control at yellow stage. Moretti *et al*. (2002) stated that pigment synthesis and expression appeared to be delayed when 1-MCP was applied at early stages of maturity and in tomato, later maturities were

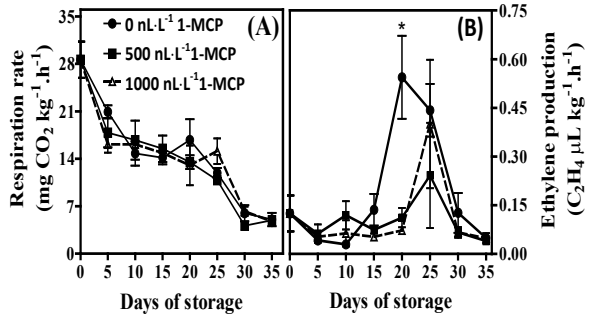

Figure 4. Changes in respiration rate (A) and ethylene production (B) of gac fruit treated with different dosages of 1-MCP and stored at 10ºC. Data represent means ± SE of four replications

demonstrated to be less affected by 1-MCP treatment (Ergun *et al*., 2006).

Effects of 1-MCP on physiological responses of gac fruit

The respiration rate of gac fruit treated with 1-MCP was the highest on the first day of storage and it gradually decreased during storage period. Although CO_2 production was not consistently affected by 1-MCP at the yellow stage throughout the experimental period, 1-MCP-treated fruit showed an average respiration rate lower than that in untreated fruit. A slight increase of CO_2 from gac was observed when the fruit started to ripen. The 1-MCP delayed the increase of respiration rate, however, the magnitude of CO_2 was not significant among all treatments (Figure 4A). The 1-MCP treatments in most products decreased or delayed the respiration rate, decrease or delay in especially in climacteric fruits. In contrast, 1- MCP had no effect on nectarine and apricot (Dong *et al.*, 2001; 2002) and arazá fruit (Carrillo *et al.*, 2011). The respiration, however, appeared to be inhibited in 1-MCP treated broccoli as a function of its concentration (Fan and Mattheis, 2000). The ethylene production of gac fruit treated with 1-MCP is shown in Figure 4B. The ethylene production decreased in all treatment during the first 10 DOS and then gradually increased and reached the maximum on 20th DOS in control fruit and 25th DOS in fruit treated with 1-MCP when the fruit became ripe. The magnitude of ethylene production of gac fruit treated with 1000 nL·L^{-1} 1- MCP was higher than that in 500 nL·L^{-1} 1-MCP on 25th DOS. It has been suggested that the competitive binding of 1-MCP to the ethylene binding site may suppress an auto-inhibitory or other feedback mechanism, allowing ethylene production to increase. Effect of 1-MCP on the ethylene production may be increased or decreased depending on types of produce (Watkins, 2006). 1-MCP lowered ethylene production in strawberry (Jiang *et al.*, 2001), slowed ethylene production in apricots and plums (Dong *et al.*, 2002), and inhibited ethylene production in Fuji apple (Fan and Mattheis, 1999). In pineapple, 1-MCP treated fruit produced higher ethylene than the control (Selvarajah *et al.*, 2001). The effect of 1-MCP depends on time and concentration. The dosage and duration of treatment of 1-MCP in this experiment was not sufficient to penetrate inside the gac fruit. Thus, the effect to 1-MCP on ethylene production was not pronounced and showed no significant difference between treatments. However, the concentration of 500 nL·L^{-1} 1-MCP resulted in a lower ethylene production than that in any other treatment and it should be applied for further study.

Effects of 1-MCP on phenolics content and antioxidant activity of gac fruit

Effect of different dosages of 1-MCP on total phenolics content in different fractions (peel, pulp, and aril) of gac fruit stored at 10ºC is shown in Table 3. The highest amount of total phenolic contents was observed in aril of gac fruit followed by peel and pulp. The total phenolic contents in peel and aril of gac fruit increased 5 days after storage and then gradually decreased during the storage and there was no significant difference between treatments except at 25 and 35 DOS in aril. Cheng *et al*. (2012) observed that all Nangou pear fruit treated with 1-MCP showed a relatively lower total phenolics content than that in control.

Effects of different dosages of 1-MCP on antioxidant activity measured by FRAP assay in different fractions (peel, pulp, and aril) of gac fruit stored at 10ºC are presented in Table 4. The highest value of antioxidant activity was observed in peel of gac fruit followed by aril and pulp. The antioxidant activity in gac increased at 5 and 15 DOS and then decreased. There was not significant difference in antioxidant activity between treatments. The highest value of antioxidant activity was found in 1000 nL·L^{-1} 1-MCP treated fruit. The findings of the present study are consistent with those of Vilaplana and Valentines (2006) in which no significant differences in total antioxidant activity were found between the control and the 1-MCP-treated apple fruit. Vilaplana and Valentines (2006) reported that 1-MCP did not detrimentally affect the antioxidant potential of the Golden Smoothee apple fruit and provided evidence to support the hypothesis that the beneficial effects of 1-MCP on ripening are not exclusively limited to its effect on ethylene. The dosage and duration of 1-MCP treatments in the present study did not affect the changes in postharvest characters, probably due to low concentration and short duration of 1-MCP or

Table 4. Effect of different dosages of 1-MCP on changes in antioxidant activity (measured by FRAP assays) in different fractions (peel, pulp, and aril) of gac fruit stored at 10ºC

Treatments	Antioxidant activity (TEA mg·100 g^{-1} FW)[1/]				
	Peel				
	D0	**D5**	**D15**	**D25**	**D35**
0 nL·L^{-1} (control)	447.62	323.81	365.08a	239.37b	133.97
500 nL·L^{-1}	447.62	292.06	250.79b	196.51b	118.73
1000 nL·L^{-1}	447.62	425.40	371.43a	262.86a	243.49
F-test	ns	ns	*	**	ns
CV%	9.25	36.61	13.87	9.84	46.12
	Pulp				
0 nL·L^{-1} (control)	164.13	174.57	121.90	98.73	93.17
500 nL·L^{-1}	164.13	164.29	109.68	97.14	93.02
1000 nL·L^{-1}	164.13	133.49	93.17	73.97	52.06
F-test	ns	ns	ns	ns	ns
CV%	41.43	38.04	31.60	39.32	63.84
	Aril				
0 nL·L^{-1} (control)	325.40	335.08	381.25	255.87	180.95
500 nL·L^{-1}	325.40	421.27	438.25	265.71	261.27
1000 nL·L^{-1}	325.40	418.73	425.24	240.95	232.38
F-test	ns	ns	ns	ns	ns
CV%	34.98	16.81	19.68	63.94	36.54

[1/] Means (n=4) with different lower case letters within the same column are significantly different.
ns: non significant, * Significant difference at $P \leq 0.05$, ** Significant difference at $P \leq 0.01$

even the maturity of gac fruit used in this study.

Conclusion

In conclusion, the optimum conditions for storage of gac fruit are 10ºC, 90-95% RH, as these conditions had the greatest impacts on gac fruit ripening and fruit quality, especially the fruit firmness. Fruit stored at 10 and 13ºC had a shelf life of 30 days, whereas storage at room temperature of 25ºC resulted in an acceptable quality of the fruit for 15 days. Although fruit stored at 4ºC showed acceptable characteristics considering their physical and physiological aspects, the fruit exhibited chilling injury symptoms such as peel shrinkage and collapse as well as leathery pulp at the end of the storage time. Gac fruit at yellow peel stage fumigated with 1-MCP treatments prior to 10ºC storage, showed no significant differences in fruit quality during storage. Phenolics and FRAP antioxidant activity were high in peel and aril, and lower in pulp of gac fruit. 1-MCP treatments and storage at low temperature had no effect on maintaining the bioactive components that became markedly reduced during storage.

Acknowledgements

This work was financially supported by the Greater Mekong Subregions Scholarship Program, King Mongkut's University of Technology Thonburi (KMUTT), Thailand. We also appreciate the Postharvest Technology Innovation Center, Thailand, for providing us with equipment facilities.

References

Abu Bakar, M.F., Mohamed, M., Rahmat, A. and Fry, J. 2009. Phytochemicals and antioxidant activity of different parts of bambangan *(Mangifera pajang)* and tarap *(Artocarpus odoratissimus)*. Food Chemistry 113: 479-483.

Ayala-Zavala, J.F., Wang, S.Y., Wang C.Y. and Gonzalez-Aguilar, G.A. 2004. Effect of storage temperatures on antioxidant capacity and aroma compounds in strawberry fruit. LWT- Food Science and Technology 37: 687-695.

Benzie, I.F.F. and Strain, J. 1996. The ferric reducing ability of plasma (FRAP) as a measure of "Antioxidant Power": the FRAP assay. Analytical Biochemistry 239: 70-76.

Bhande, S.D., Ravindra, M.R. and Goswami, T.K. 2008. Respiration rate of banana fruit under aerobic conditions at different storage temperatures. Journal

of Food Engineering 87: 116-123.

Biale, L.B., Young, R.E. and Olmstead, A.J. 1954. Fruit respiration and ethylene production. Plant Physiology 29: 168-174.

Blankenship, S.M. and Dole, J.M. 2003. 1-Methylcyclopropene: a review. Postharvest Biology and Technology 28: 1-25.

Carrillo, M.P., Hernández, M.S., Barrera, J., Martínez, O. and Fernández-Trujillo, J.P. 2011. 1-Methylcyclopropene delays arazá ripening and improves postharvest fruit quality. LWT - Food Science and Technology 44: 250-255.

Cheng, S., Wei, B. and Ji, S. 2012. A novel 1-methylcyclopropene treatment for quality control in Nangou pears at ambient temperature. African Journal of Agricultural Research 7 (14): 2236-2242.

Chuni, S.H., Awang, Y. and Mohamed, M.T.M. 2010. Cell wall enzymes activities and quality of calcium treated fresh-cut red flesh dragon fruit *(Hylocereus polyrhizus)*. International Journal of Agriculture and Biology 12: 713-718.

Dal Cin, V., Rizzini, F.M., Botton, A. and Tonutti, P. 2006. The ethylene biosynthetic and signal transduction pathways are differently affected by 1-MCP in apple and peach fruit. Postharvest Biology and Technology 42: 125-133.

De Castro, L.R., Cortez, L.A. and Vigneault, C. 2006. Effect of sorting, refrigeration and packaging on tomato shelf life. Journal of Food, Agriculture and Environment 4 (1): 70-74.

Ding, C.K., Chachin, K., Hamauzu, Y., Ueda, Y. and Imahori, Y. 1998. Effects of storage temperatures on physiology and quality of loquat fruit. Postharvest Biology and Technology 14: 309-315.

Dong, L., Lurie, S. and Zhou, H.W. 2002. Effect of 1-methylcyclopropene on ripening of 'Canino' apricots and 'Royal Zee' plums. Postharvest Biology and Technology 24: 135-145.

Dong, L., Zhou, H.W., Lers, A. and Lurie, S. 2001. Ethylene involvement in the cold storage disorders on 'Flavortop' nectarine. Postharvest Biology and Technology 23: 105-115.

Ergun, M., Sargent, S.A. and Huber, D.J. 2006. Postharvest quality of grape tomatoes treated with 1-methylcyclopropene at advanced ripeness stages. HortScience 41 (1): 183-187.

Fan, X. and Mattheis, J.P. 2000. Reduction of ethylene-induced physiological disorders of carrots and iceberg lettuce by 1-methylcyclopropene. HortScience 35: 1312-1314.

Fan, X., Blankenship, S.M. and Mattheis, J.P. 1999. 1-Methylcyclopropene inhibits apple ripening. Journal of the American Society for Horticultural Science 124: 690-695.

Francis, F.J. 1980. Color quality evaluation of horticultural crops. HortScience 15: 58-59.

Gajewski, M., Kowalczyk, K. and Bajer, M. 2009. The Influence of Postharvest Storage on Quality Characteristics of Fruit of Eggplant Cultivars. Notulae Botanicae Horti Agrobotanici Cluj-Napoca 37 (2): 200-205.

Gutierrez, M.S., Trinchero, G.D., Cerri, A.M., Vilella, F. and Sozzi, G.O. 2008. Different responses of goldenberry fruit treated at four maturity stages with the ethylene antagonist 1-methylcyclopropene. Postharvest Biology and Technology 48: 199-205.

Hamedani, M., Rabiei, V., Moradi, H., Ghanbari, A. and Azimi, M.R. 2012. Determination of storage duration and temperature effects on fruit quality parameters of blood orange (*Citrus sinensis* cv. Tarocco). Biharean Biologist 6 (1): 10-13.

Iwamoto, M., Okabe, H. and Yamauchi, T. 1985. Studies on the constituents of *Momordica cochinchinensis* Spreng. Chemical and Pharmaceutical Bulletin 33, 1-7.

Jeong, H., Huber, D.J. and Sargent, S.A. 2003. Delay of avocado *(Persea americana)* fruit ripening by 1-methylcyclopropene and wax treatments. Postharvest Biology and Technology 28: 247 - 257.

Jiang, Y.M., Joyce, D.C. and Terry, L.A. 2001. 1-Methylcyclcopropene treatment affects strawberry fruit decay. Postharvest Biology and Technology, 23: 227-232.

Kader, A.A. 1995. Regulation of fruit physiology by controlled/modified atmospheres. Acta Horticulturae 398: 59-70.

Kashmire, R.F. and Kader, A.A. 1978. Handling tomatoes at wholesale and retail: A guide for better quality and greater profits. Outlook 5 (3): 5-12.

Kubola, J. and Siriamornpun, S. 2011. Phytochemicals and antioxidant activity of different fruit fractions (peel, pulp, aril and seed) of Thai gac (*Momordica cochinchinensis* Spreng). Food chemistry 127: 1138-1145.

Leja, M., Marezek, A. and Ben, J. 2003: Antioxidant properties of two apple cultivars during long-term storage. Food Chemistry 80: 303-307.

Massolo, F.J., Concellon, A., Chaves, R.A. and Vicente, A.R. 2011. 1-methylcyclopropene (1-MCP) delays senescence, maintains quality and reduces browning of non-climacteric eggplant (*Solanum melongena* L.) fruit. Postharvest Biology and Technology 59: 10-15.

Moretti, C.L., Araújo, A.L., Marouelli, W.A. and Silva, W.L.C. 2002. 1-Methylcyclopropene delays tomato fruit ripening. Horticultura Brasileira 20 (4): 659-663.

Napolitano, A., Cascone, A., Granziani, G., Ferrancane, R., Scalfi, L., Divaio, C., Ritieni, A. and Fogliano, V. 2004. Influence of variety and storage on the polyphenol composition of apple flesh. Journal of Agricultural and Food Chemistry 52: 6526-6531.

Nunes, P.X., Silva, S.F., Guedes, R.J. and Almeida, S. 2012. Biological oxidations and antioxidant activity of natural products. Phytochemicals as nutraceuticals - Global Approaches to Their Role in Nutrition and Health.

Nyanjage, M.O., Nyalala, S.P.O., Illa, A.O., Mugo, B.W., Limbe, A.E. and Vulimu, E.M. 2005. Extending postharvest life of sweet pepper (*Capsicum annum* L. 'California Wonder') with modified atmosphere packaging and storage temperature. Agricultura

Tropica et Subtropica 38: 28-34.

Pinelo, M., Manzocco, L., Nunez, M.J. and Nicoli, M.C. 2004. Interaction among phenols in food fortification: negative synergism on antioxidant capacity. Journal of Agricultural and Food Chemistry 52: 1177-1180.

Porat, R., Weiss, B., Cohen, L., Daus, A., Goren, R. and Droby, S., 1999. Effects of ethylene and 1-methylcyclopropene on the postharvest qualities of 'Shamouti' oranges. Postharvest Biology and Technology 15: 155-163.

Pretel, M.T., Serrano, M., Amoros, A., Riquelme, F. and Romojaro, F. 1995. Noninvolvement of ACC and ACC oxidase in pepper fruit ripening. Postharvest Biology and Technology 5: 295-302.

Ramana Rao, T.V., Gol, N.B. and Shah, K.K. 2011. Effect of postharvest treatments and storage temperatures on the quality and shelf life of sweet pepper (*Capsicum annum* L.). Scientia Horticulturae 132: 18-26.

Rivera-Pastrana, D.M., Yahia E.M. and González-Aguilar G.A. 2010. Phenolic and carotenoid profiles of papaya fruit (*Carica papaya* L.) and their contents under low temperature storage. Journal of the Science of Food and Agriculture 90 (14): 2358-2365.

Roura, S.I., Davidovich, L.A. and Valle, C.E. 2000. Quality loss in minimally processed Swiss chard related to amount of damaged area. Lebensmittel Wissenschaft und Technologie 33: 53-59.

Selvarajah, S., Bauchot, A.D. and John, P. 2001 Internal browning in cold-stored pineapples is suppressed by a postharvest application of 1-methylcyclopropene. Postharvest Biology and Technology 23: 167-170.

Sisler, E.C. and Serek, M. 1997. Inhibitors of ethylene responses in plant at the receptor level: recent developments. Physiologia Plantarum 100: 577-582.

Soe Win, Kanlayanarat, S., Buanong M. and Wongs-Aree, C. 2015. Changes in quality and antioxidant activity of gac fruit (*Momordica cochinchinensis* Spreng) under low temperature storage. Acta Horticulturae (in print).

Sozzi, G.O. and Beaudry, R.M. 2007. Current perspectives on the use of 1-methylcyclopropene in tree fruit crops: an international survey. Stewart Postharvest Review 3 (2): 1-16.

Tassoni, A., Watkins, C.B. and Davies, P.J. 2006. Inhibition of the ethylene response by 1-MCP in tomato suggests that polyamines are not involved in delaying ripening, but may moderate the rate of ripening or over-ripening. Journal of Experimental Botany 57: 3313-3325.

Tomas-Barberan, F.A. and Espin, J.C. 2001: Phenolic compounds and related enzymes determinants of quality in fruits and vegetables. Journal of the Science of Food and Agriculture 81: 853-876.

Vilaplana, R. and Valentines, M.C. 2006. Antioxidant Potential and Peroxidative State of 'Golden Smoothee' Apples Treated with 1-Methylcyclopropene. Journal of the American Society for Horticultural Science 131 (1): 104-109.

Vuong, L.T. 2000. Under-utilized beta-carotene-rich crops of Viet Nam. Food and Nutrition Bulletin 2 (2): 173-181.

Vuong, L.T., Franke, A.A., Custer, L.J. and Murphy, S.P. 2006. *Momordica cochinchinensis* Spreng. (gac) fruit carotenoids reevaluated. Journal of Food Composition and Analysis 19: 664-668.

Vuong, L.T., Dueker, S.R., Murphy, S.P. 2002. Plasma beta-carotene and retinol concentrations of children increase after a 30-d supplementation with the fruit *Momordica cochinchinensis* (gac). American Journal of Clinical Nutrition 75 (5): 872-879.

Watada, A.E., Ko, N. P. and Minott, D. A. 1996. Factors affecting quality of fresh-cut horticultural products. Postharvest Biology and Technology 9: 115-125.

Watkins, C.B. 2006. The use of 1-methylcyclopropene (1-MCP) on fruits and vegetables. Biotechnology Advances 24: 389-409.

Wills, R.B.H. and Ku, V.V.V. 2002. Use of 1-MCP to extend the time to ripen of green tomatoes and postharvest life of ripe tomatoes. Postharvest Biology and Technology 26: 85-90.