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Combined postharvest UV-C and 1-Methylcyclopropene (1-MCP) treatment, followed by storage continuously in low level of ethylene atmosphere improves the quality of Tahitian limes

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Abstract

The green Tahitian limes (*Citrus latifolia*) were exposed to 7.2 kJ/m^2 UV-C and 0.5 µL L^{-1} 1-methylcyclopropene (1-MCP) treatments both separately and in combination. After treatment, fruit were stored in ethylene free (ie air containing < 0.005 µL L^{-1}) or 0.1 µL L^{-1} ethylene at 20°C and 100% RH. The results showed that UV-C treatment delayed skin degreening and reduced endogenous ethylene production compared to untreated control fruit, however these effects reduced over the storage time. As expected, 1-MCP inhibited ethylene production, reduced calyx abscission and retained peel greenness during the storage. Both of the combination treatments, 1-MCP + UV-C and UV-C + 1-MCP reduced endogenous ethylene production and delayed skin yellowing. In all treatments, UV-C and 1-MCP resulted in lower fruit respiration rates than untreated control fruit, however this effect diminished during 7 and 14 days storage for fruits stored in air and 0.1 µL L^{-1} ethylene atmosphere, respectively. There was no difference in weight loss, SSC, TA and SSC/TA ratio between the treatments and storage conditions. The results suggest that a pre-storage UV-C treatment, followed by storage at low level of ethylene improves the quality of limes, with the additional improvement when combined with 1-MCP treatment prior or after UV-C irradiation.

Keywords : *Citrus latifolia;* quality; ethylene; respiration; colour; calyx abscission

Introduction

Green peel colour is an important quality attribute of the storage of Tahitian lime (*Citrus latifolia*) where postharvest degreening of the peel can significantly downgrade consumer acceptance. UV treatment has been reported to have beneficial effect on maintaining postharvest quality of many horticultural produce. For example treatment with UV-C (100 -280 nm) has been reported to delay ripening and senescence in non-climacteric table grapes (Cantos et al. 2002), oranges (D'hallewin et al. 1999) grapefruit (D'Hallewin et al. 2000) and climacteric mangoes (Gonzalez-Aguilar et al. 2007) and tomatoes (Liu et al. 2012). UV-C irradiation has also been reported to prevent yellowing of broccoli (Buchert et al. 2011). Specifically UV-B irradiation (280 -315 nm) treatment has been shown to maintain lime peel colour (Kaewsuksaeng et al. 2011; Srilaong et al. 2011).

The recommended storage temperature for limes is 10°C (Burns 2016) and storing fruit at higher temperatures can accelerate fruit senescence, where the main deterioration is turning the peel colour from green to yellow. Although citrus fruit only normally produce only low levels of ethylene, Goldschmidt (1998) suggested that even these small amounts may play a role in the endogenous regulation of maturation and senescence in citrus. Ethylene is a ubiquitous in the horticulture supply chain where the ethylene levels in the supermarkets have been shown to be 0.017-0.035 $\mu L\ L^{-1}$ in the wholesale markets and greater than 0.06 $\mu L\ L^{-1}$ and distribution centres (Wills et al. 2000). 1- Methylcyclopropene (1-MCP) treatment has been shown to be very effective in delaying yellowing and in extending the shelf life of West Indian limes (*Citrus aurantifolia*, Swingle) (Win et al. 2006). They reported that limes treated with 250 or 500 $nL\ L^{-1}$ 1-MCP effectively delayed yellowing for 21 days at ambient storage (24-

31°C and 73-81% RH). Also, 1-MCP treatment has also been reported to delay yellowing in other horticultural produce such as on broccoli, where showed delayed yellowing during storage after broccoli were exposed to 2.5 μL L^{-1}1-MCP (Xu et al. 2016).

The effect of UV-C irradiation combined with 1-MCP treatment followed by storage in air containing low level ethylene to stimulate the normal supply chain conditions at 20°C on postharvest senescence of limes was studied in this experiment. The aim of the experiment was to examine the single and combined effects of UV-C and 1-MCP on lime quality at 20°C in air containing low levels of ethylene (0.1 μL L^{-1}).

Materials and methods

Produce

Commercial green Tahitian limes (*Citrus latifolia*) of uniform colour, shape, and size and were free from damage were used in this experiment. The experiment was repeated two times with different batches of fruit with three replicates within each batch.

1-Methylcyclopropene (1-MCP) and UV-C treatment and storage conditions

The UV-C treatments were conducted using a custom made light proof box fitted with two germicidal lamps (Sahkyo Denki Co. Ltd G20T10 20 Watt, Low Pressure Mercury). A SED008/W detector with PIR Irradiance Calibration at 254 nm was used to monitor UV-C intensity. UV-C intensity was determined prior to treatment by measuring the light intensity (kJm^{-2}) using an International Light Technologies 1700 series research radiometer. The applied dose (kJm^{-2}) was calculated by multiplying the emitting UV light intensity with treatment time in seconds. Light intensity was evaluated several times during the experiments to ensure consistent output. The limes were placed approximately 20 cm from the UV-C light sources on one side then rotated 180°C and exposed again to ensure complete coverage. During the six minute treatment the samples received 7.2 kJm^{-2} of radiation and no increase in peel temperature was recorded using TinyTag data loggers. UV-C irradiation treatment was carried out at room temperature (20 ± 1°C) and relative humidity of about 80%, unless otherwise stated. 1-MCP (0.5 $\mu L\ L^{-1}$) was applied in a 60 L sealed drum for 24 hours at 20°C and 85% RH, using SmartFresh™ powder (AgroFresh Solutions Inc., Philadelphia, PA, USA) containing 0.34% 1-MCP as active ingredient.

Control fruits were not treated with UV-C or 1-MCP application, UV-C application of 7.2 kJm^{-2} as a single treatment or was combined with 0.5 $\mu L\ L^{-1}$ 1-MCP fumigation. For the combined treatments, 1-MCP fumigation was applied first followed by UV-C treatment 24 hours later (1-MCP + UV-C). Another treatment, UV-C was applied first and then 1-MCP was applied 24 hours later (UV-C + 1-MCP). After treatment, all fruit were stored inside the containers with continuously exposed to air (less than 0.005 $\mu L\ L^{-1}$ ethylene) in a flow through system (100 mL min^{-1}) at 20°C and 100% RH or stored inside the containers with continuously exposed to 0.1 $\mu L\ L^{-1}$ ethylene in a flow through system (100 mL/min) at 20°C 100% RH.

Determination of fruits quality attributes

Fruit were removed from storage at 7, 14, 21 and 28 days and assessed for weight loss, calyx detachment, skin colour, respiration rate, ethylene production, soluble solids content (SSC), titratable acidity (TA) and overall acceptability.

The weight loss percentages were calculated based on the initial weight of the fruit and weight after storage. Calyx detachment was assessed based on the scoring of its attachment to the fruit (1) or detachment (0). Peel colour was measured using a Minolta colorimeter (Minolta CR-400, Osaka) by hue angle value. Before measuring, the colorimeter was calibrated with a white standard calibrate plate. Each fruit, the hue value were measured the average of two points from calyx to blossom end.

The ethylene production and respiration rate was measured according to Pristijono (2007), where limes were transferred to a sealed 1500 mL glass jar at 20°C and after 2 hours incubation , a gas sample (1 mL) was collected in a syringe and the ethylene and carbon dioxide content were analysed. Ethylene was measured by injecting a gas sample into a gas chromatograph (Gow-Mac 580, Bridgewater NJ) and expressed as µL $C_2H_4.kg^{-1}.h^{-1}$. Carbon dioxide concentration was measured to within 0.1% using an ICA40 series low volume gas analysis system (International Controlled Atmosphere Ltd., Kent, UK) and expressed as mL $CO_2.kg^{-1}.h^{-1}$.

Soluble solid content (SSC), expressed as °Brix, was measured from the pressed juice of fruit with a digital refractometer (ATAGO Inc., Bellevue, WA, USA). Titratable acidity (TA), expressed as % citric acid, was determined by titrating 1 mL juice to pH 8.2 with a 0.1 N NaOH solution using an automatic titrator (Mettler Toledo T50, Switzerland).

The lime overall acceptability index were assessed visually based on the skin colour, skin glossiness or/and calyx attachment, using the following scores of 1 = severe degreening or calyx detached; 2 = severe degreening, dull skin or calyx detached; 3 = slight degreening, shiny skin and calyx detached; 4 = green, shiny skin and calyx intact; and 5 = fresh as just harvested. The overall acceptability index was calculated according to Wang et al. (2015) with slight modifications. The calculation as overall acceptability index (%) = ∑[(acceptability score) × (number of fruit at this level)] / (highest level × total number of fruit in the treatment) × 100.

Statistical analysis

The experiment was performed in a completely randomized design with three replications in each of the two batches. The initial colour of the limes of the two batches were similar, as measured by the hue angle which show no significant differences ($p<0.05$) denoting homogeneity in colour between the batches. Therefore the data from both batches were combined and analysed together for a total of six replicates for the experiment. Each replication consisted of five treatment units of untreated control (without UV-C or 1-MCP), UV-C alone, 1-MCP alone, 1-MCP + UV-C and UV-C + 1-MCP. Each treatment unit consisted of 20 fruits. The two-way ANOVA and the Least Significance Difference (LSD) tests were conducted using the SAS software (SAS Ver. 9.4, USA). Differences among means were analysed at a significance level of $p<0.05$.

Results and discussion

The initial quality of the limes at the beginning of the experiment was excellent with uniform green peel colour ; hue value of skin 118.3 ± 0.3, ethylene production rate 0.014 ± 0.001 μL C_2H_4.kg^{-1}.h^{-1}, respiration rate 12.18 ± 0.47 mL CO_2.kg^{-1}.h^{-1}, SSC 8.4 ± 0.2 °Brix and TA 5.86 ±0 .27 % citric acid.

Calyx abscission

The presence of the calyx (button) on the fruit is a good indicator of quality for many consumers. The effect of postharvest 1-MCP, UV-C and ethylene treatment on calyx retention is presented in Table 1, and the results show that in general, calyx detachment was significantly affected by UV-C, 1-MCP and ethylene treatments .After 21 days storage at 20^{o}C, the percentage of intact calyx for fruits treated with UV-C combined with 1-MCP was higher than untreated fruits in both storage atmospheres. Comparing the different storage atmospheres, fruit treated with the combination UV-C and 1-MCP and stored in 0.1 μL L^{-1} ethylene had higher calyx retention than fruits stored in air (less than 0.005 μL L^{-1} ethylene) during storage for 21 days.

Weight loss

In general, there was no difference between the different pre-storage treatments on weight loss from the limes during storage. Limes treated with UV-C and 1-MCP both separately and in combination did not significantly affect the weight loss during storage (Table 1). As expected, the different storage atmospheres did not contribute to water loss for all treatments, as all atmospheres were at 100% RH which maintained fruit weight during storage. The time in storage was a significant factor affecting weight loss, where the longer time in storage resulted in the greatest weight loss through respiration and transpiration.

Ethylene production

Limes are classified as a non-climacteric fruit which characteristically do not exhibit significant a burst of ethylene production after harvest (Burns 2016). Although non-climacteric fruits do not exhibit any clear increases in ethylene production rates during ripening, in certain cases, exposure to exogenously applied ethylene may stimulate certain ripening-related processes, such as degreening of citrus fruit (Reid 2002).

In this study, untreated fruit produced significant higher in ethylene production during storage than all other treated fruits (Fig.1). Treating limes with 7.2 kJm^{-2} UV-C alone had the higher ethylene production than other treatments, whilst ethylene production rates in fruit treated with 1-MCP alone and in combination with UV-C treatment resulted in low of ethylene production rates (Fig.1). These results show that UV-C treatment suppressed ethylene production and the additional of 1-MCP futher suppresed ethylene production, regardless the application of 1-MCP prior or after UV-C treatment. These results also show that UV-C effect associated with the ethylene synthesis due to UV-C treatment alone without ethyelene interference by combined with 1-MCP provided greater effect, especially when treated fruits were stored in ethylene-free atmosphere.

Combining the storage time data, the result showed that storage time significantly ($p<0.05$) affected the endogeneous ethylene production, where the ethylene production increased significantly after 7 days storage, and remained at the level of 0.08 $\mu L\ C_2H_4.kg^{-1}.h^{-1}$ for 28 days storage. Moreover, there was significant difference in the ethylene production rates between the two storage atmospheres, where fruits were stored in air produced higher ethylene than fruits were stored at 0.1 $\mu L\ L^{-1}$ ethylene atmosphere, with the overall ethylene production of 0.074 and 0.054 $\mu L\ C_2H_4.kg^{-1}.h^{-1}$ for fruits that were stored in air and 0.1 $\mu L\ L^{-1}$ ethylene, respectively. These results suggest that exogenous ethylene application (0.1 $\mu L\ L^{-1}$ ethylene) supressed enodgenous ethylene production rates during storage for 28 days.

Skin colour

The most important factor for marketing of Tahitian limes is the retention of the green colour of peel as this is a key determinant of consumer preference. (Kaewsuksaeng et al., 2015) Peel colour as measured by hue angle was significantly influenced by storage time and pre-storage treatment, where both UV-C and 1-MCP treatment applied separately and in combination maintained green colour of the skin during storage (Fig. 2). UV-C treatment has been reported to delay de-greening of horticultural produce. For example Costa et al. (2006) showed that broccoli treated with 10 kJm^{-2} UV-C delayed yellowing after storage at 20°C for 6 days. In this experiment, UV-C treated fruits had significantly higher in hue value (greener peel colour) than untreated fruits. The retention of peel green colour was significantly greater ($p<0.05$) when UV-C treatment was combined with 1-MCP.

For the first 14 days storage, there were no significant different between the treatments, where all fruits had similar green colour. In the later stage of storage, the 1-MCP treated fruits (alone or in combination with UV-C) maintained peel green colour. Fruits treated with UV-C alone (without 1-MCP) resulted in quicker yellowing peel colour than 1-MCP treated fruits included UV-C+1-MCP and 1-MCP+UV-C. This indicated that although UV-C delayed degreening, this effect was enhanced with 1-MCP fumigation (either prior or after UV-C treatment). However, 1-MCP treatmet alone was effcetive in maitaining peel colour. The results in agreement with previous reports by Win et al. (2006) who found that Western Indian limes treated with 500 nL L^{-1} 1-MCP retained their green peel (hue angle value 110.7) at 12 days. Other studies have also been reported that 1-MCP treatment delayed degreening in other horticultural produce such as on broccoli florets (Gómez-Lobato et al. 2012; Xu et al. 2016).

In this study, the highest hue value was obtained by application of 1-MCP prior UV-C treatment (1-MCP+UVC). The results suggest that the skin degreening may be partially ethylene dependent since 1-MCP+UV-C treated fruit had low ethylene production but produced high hue value. These results an agreement with the report by Barsan et al. (2010) and Kahlau and Bock (2008) who found that tomato skin colour changes are regulated by ethylene.

Comparing the storage conditions, the rate of green colour loss from untreated peel was relatively high and occurred more greatly in fruits stored in 0.1 $\mu L\ L^{-1}$ethylene atmosphere (Fig.2). The minimum acceptable hue value for Tahitian limes is 108 (refer to score 3 for acceptability index). In this study, the lime to reach unacceptable peel colour was 3 days guicker in fruits stored in 0.1 $\mu L\ L^{-1}$ ethylene atmosphere than stored in air. These results showed that exogenous ethylene affected the peel colour changes during storage. This result differ with previous reported by Porat et al. (1999) who reported that exogenous ethylene applied to promote degreening peel colour in citrus. The result suggests that fruits stored in atmosphere containing 0.1 $\mu L\ L^{-1}$ ethylene continuously affect the treatment of UV-C and 1-MCP both separately and in combination on degreening of lime peel.

Respiration rate

The ripening of non-climacteric fruit such as citrus are characterised without any increase in fruit respiration rate (Eaks 1970). This was also observed in this experiment (Table 3), where respiration rates across all treatments and storage times ranged from 12.6 to 19.5 mL $CO_2.kg^{-1}.h^{-1}$. After 7 days storage, the untreated fruit had significantly higher respiration rates than fruit treated with 1-MCP or 1-MCP+UVC, in both storage atmospheres. These effects remained after 14 days for fruits stored in 0.1 μL L^{-1} ethylene, however, there was no pre-storage treatment effects when the fruit were stored in air (less than 0.005 μL L^{-1} ethylene) atmosphere. This result was expected, since if the 1-MCP blocks the ethylene receptor, the respiration remained low for fruits were stored in 0.1 μL.L^{-1}ethylene atmosphere. For fruits stored in less than 0.005 μL.L^{-1}, there was no difference in respiration rate between untreated and all treated fruits. These results suggest that the respiration increased with the presence of ethylene.

Respiration rate was not greatly affected by UV-C treatment apart from a significant decrease in rate after treated fruits were stored for 14 days in air at 20°C with 13.74 ml CO_2.kg^{-1}.h^{-1}. While UV-C treated fruits were store in 0.1 μL.L^{-1} ethylene, the respiration rate was significantly lower than untreated limes, however these effects reduced over the storage time. Even though the effects of UV-C treatment alone on respiration rate were not as marked as the effect of ethylene production, these results suggest that UV-C treatment combined with 1-MCP followed by storage in air containing 0.1 μL.L^{-1} ethylene at 20°C maintained limes quality by maintaining respiration rate during storage as a natural ripening of citrus fruit.

SSC, TA and SSC/TA ratio

UV-C treatment has been reported to influence the SSC or TA in a range of horticultural produce. For example Charles et al. (2016) reported that tomatoes treated with 3.7 kJm^{-2} UV-C followed by storage at 15°C for 15 days resulted in lower sugar content and higher in acid titre than untreated fruits. The results from this study showed that in general SSC and TA were not affected by UV-C treatment alone or in combination with 1-MCP (Table2). These results are consistent with previous reports that showed exposure to 1-MCP did not affect internal properties (SSC and TA) in citrus fruit (Dou et al. 2005; Kluge et al. 2003; Porat et al. 1999; Salvador et al. 2006).

The SSC/TA ratio is an important parameter related with quality characteristics of citrus fruits (Barros et al. 2012). In this study, comparing the storage conditions, there was no difference in SSC, TA and SSC/TA ratio between limes that were stored in air (less than 0.005 μL L^{-1}) and 0.1 μL L^{-1} ethylene atmospheres. These results suggest that UV-C treatment alone or in combination with 1-MCP, followed by storage under low level ethylene can be applied without affecting the SSC or TA. Thus, UV-C alone or in combination with 1-MCP is a potential postharvest treatment for the maintaining of limes' quality during storage in actual supply chain conditions.

Acceptability index

The overall cosmetic acceptability of the limes index were assessed visually based on the skin colour, skin glossiness or/and calyx intact. The effect of UV-C and 1-MCP both separately or in combination is presented in Table 3 and the results show that fruit treated with UV-C and 1-MCP alone or in combination had higher overall acceptability than untreated fruits in both storage atmospheres.

Within the treated fruit, UV-C treatment resulted in fruit with significantly lower acceptability index than fruits treated by 1-MCP alone or in combination with 7.2 kJm^{-2} UV-C after 21 days storage in both storage atmospheres. The higher acceptability index during the earlier stages of storage (up to 21 days), may be associated with the peel colour, since after 21 days storage, UV-C treated limes were more yellow (lower hue angle). These results show that limes treated with UV-C maitained a better acceptability after 21 days storage, the greater acceptability index when combined with 0.5 μL L^{-1} 1-MCP prior or after UV-C treament.

Conclusions

Our study showed the application of 7.2 kJm^{-2} UV-C and 0.5 μL L^{-1} 1-MCP separately or in combination, followed by storage at 20°C in low level of ethylene atmosphere improved lime fruit quality compared to untreated fruit. The UV-C treatment alone improved lime fruit quality by delaying peel yellowing and this effect was greater when combined with 1-MCP. There was no significant difference effect of 1-MCP applied prior or after UV-C treatment on lime quality. The application UV-C and 1-MCP did not affect weight loss, SSC nor TA. Overall, the UV-C treatment combined with 1-MCP resulted in improved fruit quality by delaying the peel degreening, maintaining the attachment of the calyx, maintained low ethylene production and improved the acceptability index. More study is required to assess the effect of application of UV-C combined with 1-MCP, followed by storage in different temperatures (such as 10ºC) to determine if the mode of action of UV-C is similar with this study.

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Table 1. Weight loss and calyx intact percentage of limes after treated with UV-C and/or 1-MCP, followed by storage up to 28 days at 20°C.

Storage / Treatments	Weight loss (%)				Calyx intact (%)			
	day 7	day 14	day 21	day 28	day 7	day 14	day 21	day 28
< 0.005 $\mu L.L^{-1}$ ethylene								
Control	0.3^{a}	0.3^{ab}	0.5^{a}	0.7^{a}	79^{a}	67^{a}	75^{a}	58^{a}
1-MCP	0.2^{a}	0.4^{a}	0.5^{a}	0.7^{a}	96^{b}	92^{b}	88^{a}	83^{ab}
UVC	0.2^{a}	0.4^{a}	0.5^{a}	0.6^{a}	96^{b}	96^{b}	88^{a}	75^{ab}
1-MCP+UVC	0.2^{a}	0.3^{ab}	0.5^{a}	0.6^{a}	100^{b}	92^{b}	92^{b}	92^{ab}
UVC+1-MCP	0.2	0.2^{b}	0.5^{a}	0.7^{a}	100^{b}	92^{b}	92^{b}	83^{a}
0.1 $\mu L.L^{-1}$ ethylene								
Control	0.2^{a}	0.3^{a}	0.5^{a}	0.8^{a}	88^{b}	71^{a}	88^{b}	79^{ab}
1-MCP	0.2^{a}	0.3^{a}	0.4^{b}	0.6^{b}	100^{b}	96^{b}	92^{a}	79^{ab}
UVC	0.2^{a}	0.4^{a}	0.5^{a}	0.6^{b}	100^{b}	96^{b}	71^{b}	75^{b}
1-MCP+UVC	0.2^{a}	0.2^{a}	0.5^{a}	0.6^{b}	100^{b}	100^{b}	100^{a}	79^{ab}
UVC+1-MCP	0.2^{a}	0.3^{a}	0.5^{a}	0.6^{b}	100^{b}	100^{b}	100^{a}	92^{a}

Values are the mean of 6 replicates. Letters indicate mean values at the same columns, treatments and storage time that are statistically different ($P<0.05$)

Table 2. Soluble solids content (SSC) and titratable acidity (TA) of limes after treated with UV-C and/or 1-MCP, followed by storage up to 28 days at 20°C.

Storage / Treatments	SSC (°Brix)				TA (% citric acid)			
	day 7	day 14	day 21	day 28	day 7	day 14	day 21	day 28
< 0.005 $\mu L.L^{-1}$ ethylene								
Control	8.5[a]	8.2[a]	8.8[ab]	8.9[a]	6.28[a]	6.40[a]	6.54[a]	6.60[a]
1-MCP	8.8[a]	8.9[b]	8.9[a]	8.8[a]	6.37[a]	6.35[a]	6.69[a]	6.60[a]
UVC	8.7[a]	8.9[b]	8.4[b]	8.9[a]	6.65[a]	6.36[a]	6.53[a]	6.56[a]
1-MCP+UVC	8.5[a]	8.7[ab]	8.7[ab]	8.7[a]	6.45[a]	6.00[a]	6.37[a]	6.50[a]
UVC+1-MCP	9.0[a]	9.2[b]	8.9[a]	9.1[a]	6.44[a]	6.18[a]	6.35[a]	6.75[a]
0.1 $\mu L.L^{-1}$ ethylene								
Control	8.6[a]	8.7[a]	8.7[a]	8.8[a]	6.28[a]	6.43[a]	6.48[a]	6.53[a]
1-MCP	8.5[a]	8.8[a]	8.7[a]	9.0[a]	6.37[a]	6.27[a]	6.54[a]	6.40[a]
UVC	8.7[a]	8.9[a]	8.9[a]	8.9[a]	6.34[a]	6.52[a]	6.15[a]	6.66[a]
1-MCP+UVC	8.8[a]	9.0[a]	8.7[a]	9.0[a]	6.33[a]	6.61[a]	6.82[a]	6.44[a]
UVC+1-MCP	8.8[a]	9.0[a]	8.7[a]	9.0[a]	6.36[a]	6.47[a]	6.45[a]	6.64[a]

Values are the mean of 6 replicates. Letters indicate mean values at the same columns, treatments and storage time that are statistically different ($P<0.05$)

Table 3. Respiration rate and acceptability index of limes after treated with UV-C and/or 1-MCP, followed by storage up to 28 days at 20°C.

Storage / Treatments	Respiration rate ($mlCO_2.kg^{-1}.hr^{-1}$)				Acceptability index (%)			
	day 7	day 14	day 21	day 28	day 7	day 14	day 21	day 28
< 0.005 $\mu L.L^{-1}$ ethylene								
Control	18.61^{a}	14.78^{a}	16.82^{a}	18.65^{a}	60^{a}	43^{a}	33^{c}	22^{c}
1-MCP	13.68^{b}	13.83^{a}	15.45^{a}	16.00^{ab}	74^{b}	68^{b}	67^{a}	43^{a}
UVC	14.66^{ab}	13.74^{a}	15.73^{a}	16.88^{ab}	79^{b}	66^{b}	50^{b}	38^{b}
1-MCP+UVC	13.98^{b}	13.51^{a}	14.12^{a}	13.95^{b}	77^{b}	75^{b}	64^{a}	43^{a}
UVC+1-MCP	15.19^{ab}	13.89^{a}	15.23^{a}	16.05^{ab}	85^{b}	77^{b}	68^{a}	43^{a}
0.1 $\mu L.L^{-1}$ ethylene								
Control	19.06^{a}	16.84^{a}	16.69^{a}	19.46^{a}	54^{a}	35^{c}	30^{c}	23^{c}
1-MCP	13.80^{b}	13.57^{b}	15.52^{a}	17.37^{ab}	78^{b}	66^{b}	58^{a}	39^{ab}
UVC	14.98^{b}	13.66^{b}	15.53^{a}	17.42^{ab}	80^{b}	68^{ab}	48^{b}	34^{bc}
1-MCP+UVC	14.10^{b}	12.63^{b}	15.37^{a}	15.32^{b}	77^{b}	73^{ab}	63^{a}	51^{a}
UVC+1-MCP	17.88^{ab}	14.73^{ab}	15.60^{a}	18.35^{a}	81^{b}	77^{a}	62^{a}	45^{ab}

Values are the mean of 6 replicates. Letters indicate mean values at the same columns, treatments and storage time that are statistically different ($P<0.05$)

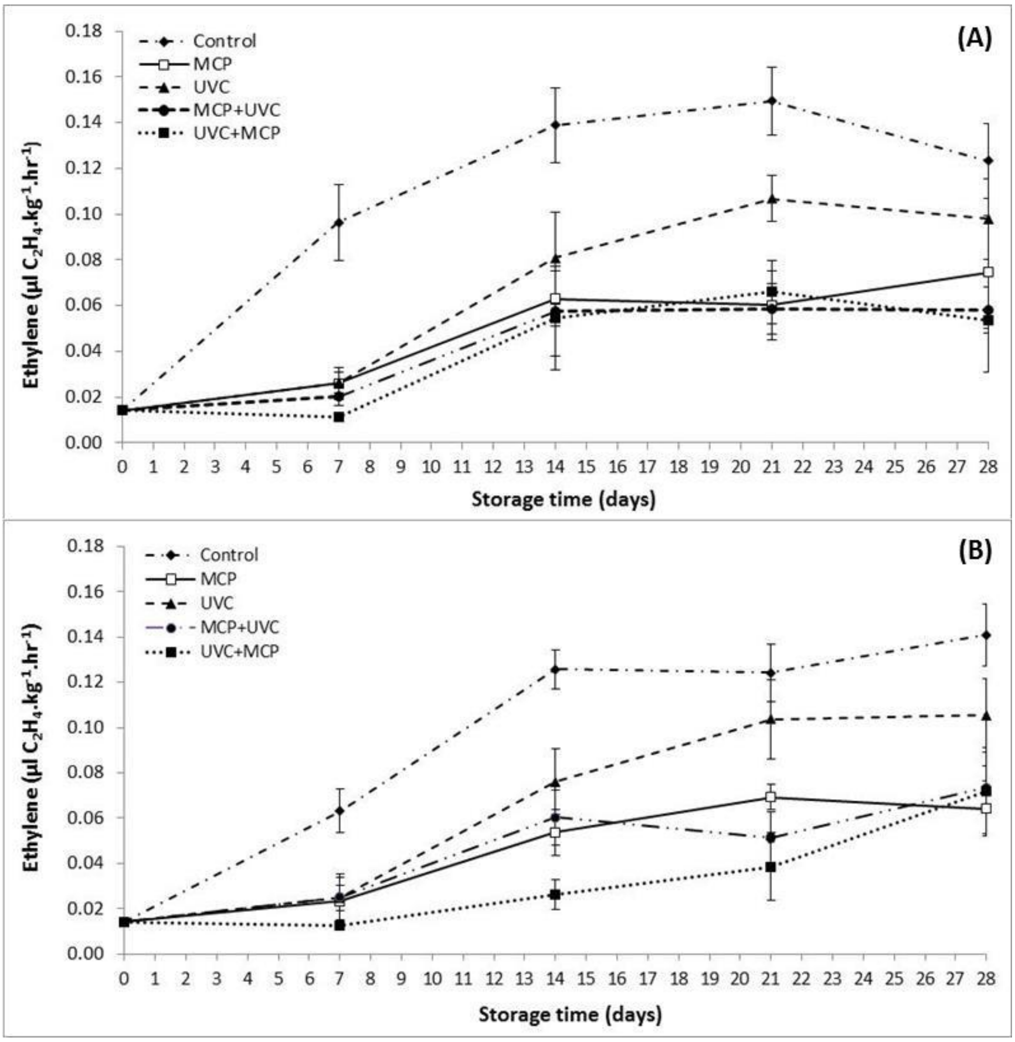

Figure 1 Ethylene production of limes after treated with UV-C and/or 1-MCP, followed by storage in air containing (A) < 0.005 μL.L^{-1} ethylene and (B) 0.1 μL.L^{-1} ethylene at 20°C.

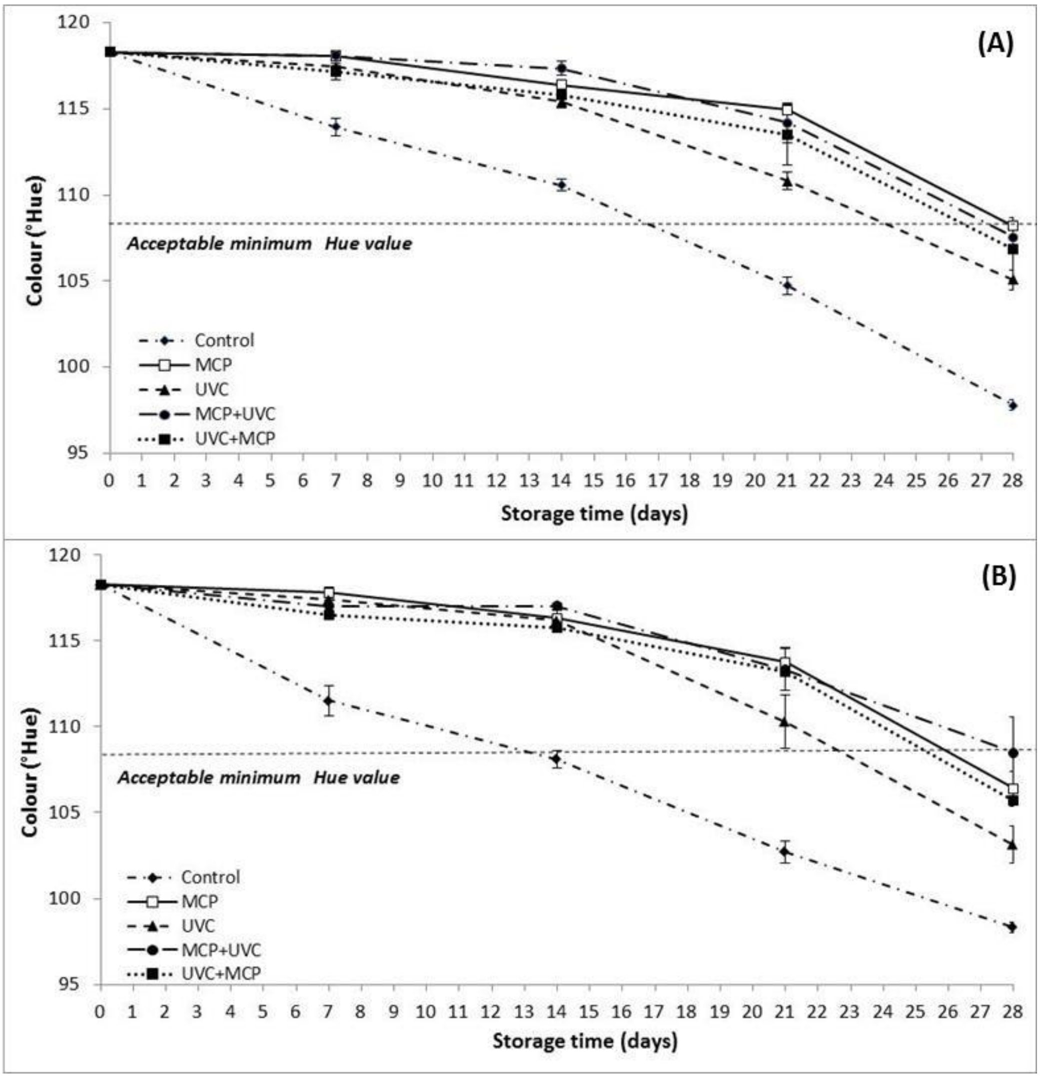

Figure 2 Peel colour (°Hue) of limes after treated with UV-C and/or 1-MCP, followed by storage in air containing (A) < 0.005 $\mu L.L^{-1}$ ethylene and (B) 0.1 $\mu L.L^{-1}$ ethylene at 20°C.