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

4

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22

23 **Abstract**

24 The green Tahitian limes (*Citrus latifolia*) were exposed to 7.2 kJ/m² UV-C and 0.5 μL
25 L⁻¹ 1-methylcyclopropene (1-MCP) treatments both separately and in combination.
26 After treatment, fruit were stored in ethylene free (ie air containing < 0.005 μL L⁻¹) or
27 0.1 μL L⁻¹ ethylene at 20°C and 100% RH. The results showed that UV-C treatment
28 delayed skin degreening and reduced endogenous ethylene production compared to
29 untreated control fruit, however these effects reduced over the storage time. As
30 expected, 1-MCP inhibited ethylene production, reduced calyx abscission and retained
31 peel greenness during the storage. Both of the combination treatments, 1-MCP + UV-C
32 and UV-C + 1-MCP reduced endogenous ethylene production and delayed skin
33 yellowing. In all treatments, UV-C and 1-MCP resulted in lower fruit respiration rates
34 than untreated control fruit, however this effect diminished during 7 and 14 days storage
35 for fruits stored in air and 0.1 μL L⁻¹ ethylene atmosphere, respectively. There was no
36 difference in weight loss, SSC, TA and SSC/TA ratio between the treatments and
37 storage conditions. The results suggest that a pre-storage UV-C treatment, followed by
38 storage at low level of ethylene improves the quality of limes, with the additional
39 improvement when combined with 1-MCP treatment prior or after UV-C irradiation.

40

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

42 **Introduction**

43 Green peel colour is an important quality attribute of the storage of Tahitian lime
44 (*Citrus latifolia*) where postharvest degreening of the peel can significantly downgrade
45 consumer acceptance. UV treatment has been reported to have beneficial effect on
46 maintaining postharvest quality of many horticultural produce. For example treatment
47 with UV-C (100 -280 nm) has been reported to delay ripening and senescence in non-
48 climacteric table grapes (Cantos et al. 2002), oranges (D'hallewin et al. 1999) grapefruit
49 (D'Hallewin et al. 2000) and climacteric mangoes (Gonzalez-Aguilar et al. 2007) and
50 tomatoes (Liu et al. 2012). UV-C irradiation has also been reported to prevent yellowing
51 of broccoli (Buchert et al. 2011). Specifically UV-B irradiation (280 -315 nm) treatment
52 has been shown to maintain lime peel colour (Kaewsuksaeng et al. 2011; Srilaong et al.
53 2011).

54 The recommended storage temperature for limes is 10°C (Burns 2016) and
55 storing fruit at higher temperatures can accelerate fruit senescence, where the main
56 deterioration is turning the peel colour from green to yellow. Although citrus fruit only
57 normally produce only low levels of ethylene, Goldschmidt (1998) suggested that even
58 these small amounts may play a role in the endogenous regulation of maturation and
59 senescence in citrus. Ethylene is a ubiquitous in the horticulture supply chain where the
60 ethylene levels in the supermarkets have been shown to be 0.017-0.035 $\mu\text{L L}^{-1}$ in the
61 wholesale markets and greater than 0.06 $\mu\text{L L}^{-1}$ and distribution centres (Wills et al.
62 2000). 1- Methylcyclopropene (1-MCP) treatment has been shown to be very effective
63 in delaying yellowing and in extending the shelf life of West Indian limes (*Citrus*
64 *aurantifolia*, Swingle) (Win et al. 2006). They reported that limes treated with 250 or
65 500 nL L⁻¹ 1-MCP effectively delayed yellowing for 21 days at ambient storage (24-

66 31°C and 73-81% RH). Also, 1-MCP treatment has also been reported to delay
67 yellowing in other horticultural produce such as on broccoli, where showed delayed
68 yellowing during storage after broccoli were exposed to 2.5 $\mu\text{L L}^{-1}$ 1-MCP (Xu et al.
69 2016).

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

75

76 **Materials and methods**

77 **Produce**

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

81

82 **1-Methylcyclopropene (1-MCP) and UV-C treatment and storage conditions**

83 The UV-C treatments were conducted using a custom made light proof box fitted with
84 two germicidal lamps (Sahkyo Denki Co. Ltd G20T10 20 Watt, Low Pressure
85 Mercury). A SED008/W detector with PIR Irradiance Calibration at 254 nm was used
86 to monitor UV-C intensity. UV-C intensity was determined prior to treatment by
87 measuring the light intensity (kJm^{-2}) using an International Light Technologies 1700
88 series research radiometer. The applied dose (kJm^{-2}) was calculated by multiplying the
89 emitting UV light intensity with treatment time in seconds. Light intensity was

90 evaluated several times during the experiments to ensure consistent output. The limes
91 were placed approximately 20 cm from the UV-C light sources on one side then rotated
92 180°C and exposed again to ensure complete coverage. During the six minute treatment
93 the samples received 7.2 kJm⁻² of radiation and no increase in peel temperature was
94 recorded using TinyTag data loggers. UV-C irradiation treatment was carried out at
95 room temperature (20 ± 1°C) and relative humidity of about 80%, unless otherwise
96 stated. 1-MCP (0.5 µL L⁻¹) was applied in a 60 L sealed drum for 24 hours at 20°C and
97 85% RH, using SmartFresh™ powder (AgroFresh Solutions Inc., Philadelphia, PA,
98 USA) containing 0.34% 1-MCP as active ingredient.

99 Control fruits were not treated with UV-C or 1-MCP application, UV-C
100 application of 7.2 kJm⁻² as a single treatment or was combined with 0.5 µL L⁻¹ 1-MCP
101 fumigation. For the combined treatments, 1-MCP fumigation was applied first followed
102 by UV-C treatment 24 hours later (1-MCP + UV-C). Another treatment, UV-C was
103 applied first and then 1-MCP was applied 24 hours later (UV-C + 1-MCP). After
104 treatment, all fruit were stored inside the containers with continuously exposed to air
105 (less than 0.005 µL L⁻¹ ethylene) in a flow through system (100 mL min⁻¹) at 20°C and
106 100% RH or stored inside the containers with continuously exposed to 0.1 µL L⁻¹
107 ethylene in a flow through system (100 mL/min) at 20°C 100% RH.

108

109 **Determination of fruits quality attributes**

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

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

119 The ethylene production and respiration rate was measured according to
120 Pristijono (2007), where limes were transferred to a sealed 1500 mL glass jar at 20°C
121 and after 2 hours incubation , a gas sample (1 mL) was collected in a syringe and the
122 ethylene and carbon dioxide content were analysed. Ethylene was measured by injecting
123 a gas sample into a gas chromatograph (Gow-Mac 580, Bridgewater NJ) and expressed
124 as $\mu\text{L C}_2\text{H}_4.\text{kg}^{-1}.\text{h}^{-1}$. Carbon dioxide concentration was measured to within 0.1% using
125 an ICA40 series low volume gas analysis system (International Controlled Atmosphere
126 Ltd., Kent, UK) and expressed as $\text{mL CO}_2.\text{kg}^{-1}.\text{h}^{-1}$.

127 Soluble solid content (SSC), expressed as °Brix, was measured from the pressed
128 juice of fruit with a digital refractometer (ATAGO Inc., Bellevue, WA, USA).

129 Titratable acidity (TA), expressed as % citric acid, was determined by titrating 1 mL
130 juice to pH 8.2 with a 0.1 N NaOH solution using an automatic titrator (Mettler Toledo
131 T50, Switzerland).

132 The lime overall acceptability index were assessed visually based on the skin
133 colour, skin glossiness or/and calyx attachment, using the following scores of 1 = severe
134 degreening or calyx detached; 2 = severe degreening, dull skin or calyx detached; 3 =
135 slight degreening, shiny skin and calyx detached; 4 = green, shiny skin and calyx intact;
136 and 5 = fresh as just harvested. The overall acceptability index was calculated according

137 to Wang et al. (2015) with slight modifications. The calculation as overall acceptability
138 index (%) = $\sum[(\text{acceptability score}) \times (\text{number of fruit at this level})] / (\text{highest level} \times$
139 $\text{total number of fruit in the treatment}) \times 100.$

140

141 **Statistical analysis**

142 The experiment was performed in a completely randomized design with three
143 replications in each of the two batches. The initial colour of the limes of the two batches
144 were similar, as measured by the hue angle which show no significant differences
145 ($p < 0.05$) denoting homogeneity in colour between the batches. Therefore the data from
146 both batches were combined and analysed together for a total of six replicates for the
147 experiment. Each replication consisted of five treatment units of untreated control
148 (without UV-C or 1-MCP), UV-C alone, 1-MCP alone, 1-MCP + UV-C and UV-C + 1-
149 MCP. Each treatment unit consisted of 20 fruits. The two-way ANOVA and the Least
150 Significance Difference (LSD) tests were conducted using the SAS software (SAS Ver.
151 9.4, USA). Differences among means were analysed at a significance level of $p < 0.05$.

152

153 **Results and discussion**

154 The initial quality of the limes at the beginning of the experiment was excellent with
155 uniform green peel colour ; hue value of skin 118.3 ± 0.3 , ethylene production rate
156 $0.014 \pm 0.001 \mu\text{L C}_2\text{H}_4.\text{kg}^{-1}.\text{h}^{-1}$, respiration rate $12.18 \pm 0.47 \text{ mL CO}_2.\text{kg}^{-1}.\text{h}^{-1}$, SSC 8.4
157 ± 0.2 °Brix and TA 5.86 ± 0.27 % citric acid.

158

159 **Calyx abscission**

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

169

170 **Weight loss**

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

179

180 **Ethylene production**

181 Limes are classified as a non-climacteric fruit which characteristically do not exhibit
182 significant a burst of ethylene production after harvest (Burns 2016). Although non-
183 climacteric fruits do not exhibit any clear increases in ethylene production rates during

184 ripening, in certain cases, exposure to exogenously applied ethylene may stimulate
185 certain ripening-related processes, such as degreening of citrus fruit (Reid 2002).

186 In this study, untreated fruit produced significant higher in ethylene production
187 during storage than all other treated fruits (Fig.1). Treating limes with 7.2 kJm^{-2} UV-C
188 alone had the higher ethylene production than other treatments, whilst ethylene
189 production rates in fruit treated with 1-MCP alone and in combination with UV-C
190 treatment resulted in low of ethylene production rates (Fig.1). These results show that
191 UV-C treatment suppressed ethylene production and the additional of 1-MCP further
192 suppressed ethylene production, regardless the application of 1-MCP prior or after UV-C
193 treatment. These results also show that UV-C effect associated with the ethylene
194 synthesis due to UV-C treatment alone without ethylene interference by combined with
195 1-MCP provided greater effect, especially when treated fruits were stored in ethylene-
196 free atmosphere.

197 Combining the storage time data, the result showed that storage time
198 significantly ($p < 0.05$) affected the endogenous ethylene production, where the ethylene
199 production increased significantly after 7 days storage, and remained at the level of 0.08
200 $\mu\text{L C}_2\text{H}_4.\text{kg}^{-1}.\text{h}^{-1}$ for 28 days storage. Moreover, there was significant difference in the
201 ethylene production rates between the two storage atmospheres, where fruits were
202 stored in air produced higher ethylene than fruits were stored at $0.1 \mu\text{L L}^{-1}$ ethylene
203 atmosphere, with the overall ethylene production of 0.074 and $0.054 \mu\text{L C}_2\text{H}_4.\text{kg}^{-1}.\text{h}^{-1}$
204 for fruits that were stored in air and $0.1 \mu\text{L L}^{-1}$ ethylene, respectively. These results
205 suggest that exogenous ethylene application ($0.1 \mu\text{L L}^{-1}$ ethylene) suppressed
206 endogenous ethylene production rates during storage for 28 days.

207

208 **Skin colour**

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

220 For the first 14 days storage, there were no significant different between the
221 treatments, where all fruits had similar green colour. In the later stage of storage, the 1-
222 MCP treated fruits (alone or in combination with UV-C) maintained peel green colour.
223 Fruits treated with UV-C alone (without 1-MCP) resulted in quicker yellowing peel
224 colour than 1-MCP treated fruits included UV-C+1-MCP and 1-MCP+UV-C. This
225 indicated that although UV-C delayed degreening, this effect was enhanced with 1-
226 MCP fumigation (either prior or after UV-C treatment). However, 1-MCP treatmet
227 alone was effctive in maitaining peel colour. The results in agreement with previous
228 reports by Win et al. (2006) who found that Western Indian limes treated with 500 nL L^{-1}
229 ¹ 1-MCP retained their green peel (hue angle value 110.7) at 12 days. Other studies have
230 also been reported that 1-MCP treatment delayed degreening in other horticultural
231 produce such as on broccoli florets (Gómez-Lobato et al. 2012; Xu et al. 2016).

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

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

249

250 **Respiration rate**

251 The ripening of non-climacteric fruit such as citrus are characterised without any
252 increase in fruit respiration rate (Eaks 1970). This was also observed in this experiment
253 (Table 3), where respiration rates across all treatments and storage times ranged from
254 12.6 to 19.5 $\text{mL CO}_2.\text{kg}^{-1}.\text{h}^{-1}$. After 7 days storage, the untreated fruit had significantly
255 higher respiration rates than fruit treated with 1-MCP or 1-MCP+UVC, in both storage

256 atmospheres. These effects remained after 14 days for fruits stored in $0.1 \mu\text{L L}^{-1}$
257 ethylene, however, there was no pre-storage treatment effects when the fruit were
258 stored in air (less than $0.005 \mu\text{L L}^{-1}$ ethylene) atmosphere. This result was expected,
259 since if the 1-MCP blocks the ethylene receptor, the respiration remained low for fruits
260 were stored in $0.1 \mu\text{L.L}^{-1}$ ethylene atmosphere. For fruits stored in less than 0.005
261 $\mu\text{L.L}^{-1}$, there was no difference in respiration rate between untreated and all treated
262 fruits. These results suggest that the respiration increased with the presence of ethylene.

263 Respiration rate was not greatly affected by UV-C treatment apart from a
264 significant decrease in rate after treated fruits were stored for 14 days in air at 20°C with
265 $13.74 \text{ ml CO}_2.\text{kg}^{-1}.\text{h}^{-1}$. While UV-C treated fruits were store in $0.1 \mu\text{L.L}^{-1}$ ethylene, the
266 respiration rate was significantly lower than untreated limes, however these effects
267 reduced over the storage time. Even though the effects of UV-C treatment alone on
268 respiration rate were not as marked as the effect of ethylene production, these results
269 suggest that UV-C treatment combined with 1-MCP followed by storage in air
270 containing $0.1 \mu\text{L.L}^{-1}$ ethylene at 20°C maintained limes quality by maintaining
271 respiration rate during storage as a natural ripening of citrus fruit.

272

273 **SSC, TA and SSC/TA ratio**

274 UV-C treatment has been reported to influence the SSC or TA in a range of horticultural
275 produce. For example Charles et al. (2016) reported that tomatoes treated with 3.7 kJm^{-2}
276 UV-C followed by storage at 15°C for 15 days resulted in lower sugar content and
277 higher in acid titre than untreated fruits. The results from this study showed that in
278 general SSC and TA were not affected by UV-C treatment alone or in combination with
279 1-MCP (Table2). These results are consistent with previous reports that showed

280 exposure to 1-MCP did not affect internal properties (SSC and TA) in citrus fruit (Dou
281 et al. 2005; Kluge et al. 2003; Porat et al. 1999; Salvador et al. 2006).

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

290

291 **Acceptability index**

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

297 Within the treated fruit, UV-C treatment resulted in fruit with significantly
298 lower acceptability index than fruits treated by 1-MCP alone or in combination with
299 7.2 kJm^{-2} UV-C after 21 days storage in both storage atmospheres. The higher
300 acceptability index during the earlier stages of storage (up to 21 days), may be
301 associated with the peel colour, since after 21 days storage, UV-C treated limes were
302 more yellow (lower hue angle). These results show that limes treated with UV-C

303 maintained a better acceptability after 21 days storage, the greater acceptability index
304 when combined with 0.5 $\mu\text{L L}^{-1}$ 1-MCP prior or after UV-C treatment.

305

306 **Conclusions**

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

319

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325

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419

420 **Table 1.** Weight loss and calyx intact percentage of limes after treated with UV-C

421 and/or 1-MCP, followed by storage up to 28 days at 20°C.

422

Storage / Treatments	Weight loss (%)				Calyx intact (%)			
	day 7	day 14	day 21	day 28	day 7	day 14	day 21	day 28
<i>< 0.005 μL.L⁻¹ ethylene</i>								
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
<i>0.1 μL.L⁻¹ ethylene</i>								
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)

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426 **Table 2.** Soluble solids content (SSC) and titratable acidity (TA) of limes after treated
 427 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
<i>< 0.005 μL.L⁻¹ ethylene</i>								
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
<i>0.1 μL.L⁻¹ ethylene</i>								
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)

428
429

430 **Table 3.** Respiration rate and acceptability index of limes after treated with UV-C

431 and/or 1-MCP, followed by storage up to 28 days at 20°C.

432

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
<u>< 0.005 μL.L⁻¹ ethylene</u>								
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
<u>0.1 μL.L⁻¹ ethylene</u>								
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)

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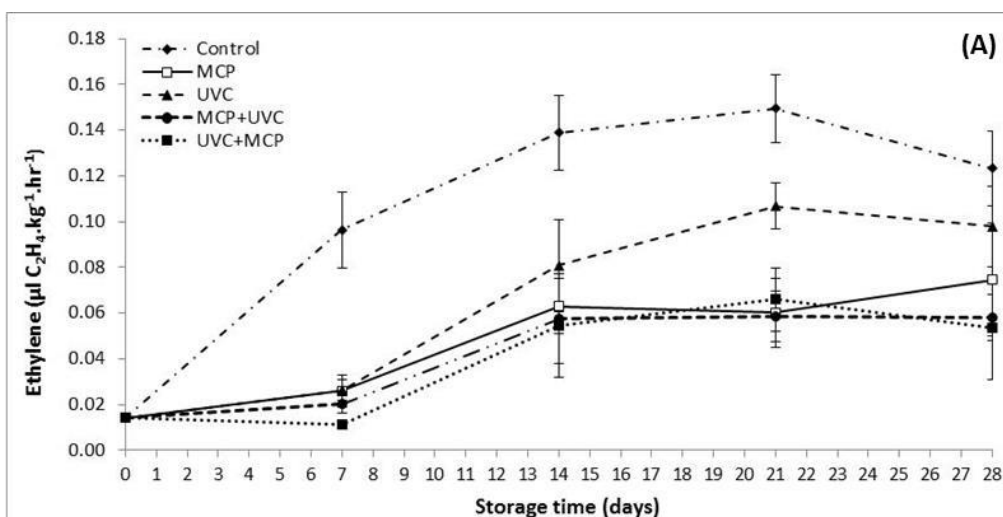
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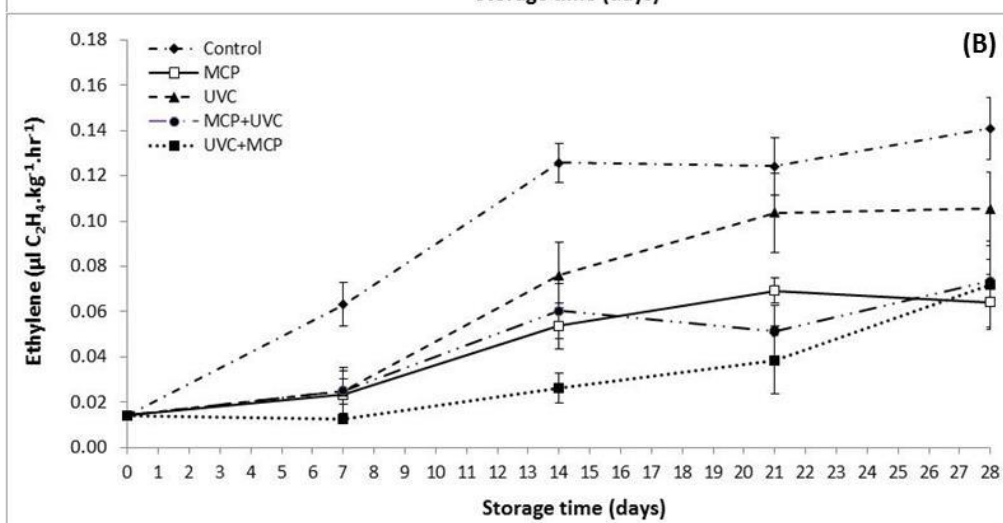
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Figure 1 Ethylene production of limes after treated with UV-C and/or 1-MCP,

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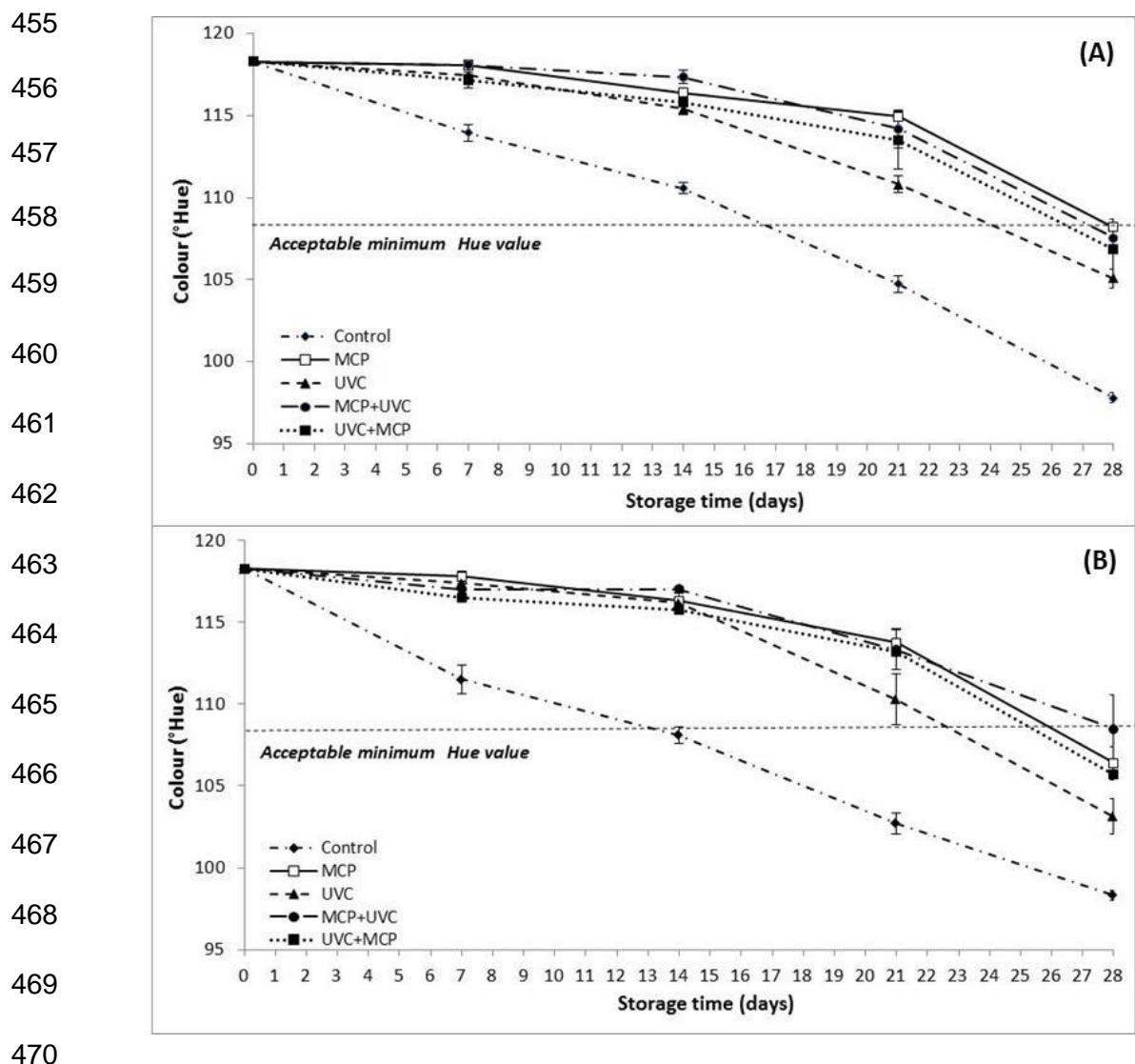
followed by storage in air containing (A) $< 0.005 \mu\text{L.L}^{-1}$ ethylene and (B) $0.1 \mu\text{L.L}^{-1}$

452

ethylene at 20°C .

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454



471 **Figure 2** Peel colour (°Hue) of limes after treated with UV-C and/or 1-MCP, followed
 472 by storage in air containing (A) $< 0.005 \mu\text{L.L}^{-1}$ ethylene and (B) $0.1 \mu\text{L.L}^{-1}$ ethylene at
 473 20°C .
 474