Postharvest UV-C treatment combined with 1-methylcyclopropene (1-MCP), followed by storage in continuous low level ethylene atmosphere improves the quality of tomatoes.

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Abstract

Mature green tomatoes (*Solanum lycopersicum cv* Neang Pich) were exposed to 13.6 kJm^{-2} UV-C or 0.5 $\mu l\ l^{-1}$ 1-MCP or combination of 13.6 kJm^{-2} UV-C and 0.5 $\mu l\ l^{-1}$ 1-MCP, with appropriate untreated controls. After treatment, tomatoes were stored in continuous air containing 0.1 $\mu l\ l^{-1}$ ethylene at 20°C and 100% RH. The untreated fruit ripened significantly faster than all other treatments. UV-C treatment alone was able to delay fruit ripening by up to five days longer compared to untreated fruits whilst the additional of 1-MCP further delayed fruit ripening. UV-C and 1-MCP treatments alone or in combination had significantly slower ethylene production rates throughout the storage period. The fruit treated with the combination of 1-MCP and UV-C was significantly firmer and had higher in total phenolic content compared to the other treatments. However, there was no difference between treatments in SSC/TA ratio, chlorophyll content, lycopene content and total antioxidant activity. These results show that UV-C and 1-MCP treatment delay ripening and improve the quality of tomatoes in the presence of low level ethylene during storage. This new treatment could be used to extend the shelf-life of mature green tomatoes through the supply chain without the use of refrigeration.

Keywords : *Solanum lycopersicum,* ethylene, ripening, chlorophyll, lycopene, total antioxidant, total phenolic content.

Introduction

The tomato is the world's most widely consumed vegetable (Scibisz et al., 2011). In many countries, tomato production is largely aimed at the fresh-produce market and therefore requires close management of ripening and the supply chain to ensure optimal external and internal quality (De Oliveira et al., 2014).

Tomatoes are highly perishable and as for most climacteric fruits, anticipating harvest before the climacteric rise is considered the best strategy to prolong shelf-life and reduce the spoilage rate (Saltveit, 2005). However this practice can also negatively affect taste and nutritional quality as fruit picked at the mature green stage or before turning to red colour, although able to continue the ripening process, generally develop poor eating and nutritional traits when fully ripened (Kader, 1986). The tomato fruit is composed mainly of water, soluble and insoluble solids, organic acids (principally citric acid) and micronutrients such as carotenoids and vitamins A and C (Pedro & Ferreira, 2007). Sugars and organic acids are responsible for sweetness and tartness, and also influence tomato flavour; as a result, they are the major factors affecting consumer acceptability (Kader, 2008). Colour also has a marked influence on the initial purchasing decision by consumers, who tend to link fruit colour to taste quality (Causse et al., 2010).

Treatment with UV-C (180 -280 nm) after harvest has been shown to reduce pathogen growth (Guerrero-Beltrán & Barbosa-Cánovas, 2004) and has been reported to extend the postharvest shelf-life of tomatoes by delayed fruit softening (Liu et al., 2011). UV-C treatment has also been shown to delay ripening and senescence in table grapes (Cantos & Tomás-Barberán, 2002), oranges (D'hallewin et al., 1999), peaches (Gonzalez-Aguilar et al., 2004) and mangoes (Gonzalez-Aguilar et al., 2007). Therefore, postharvest

65 UV-C treatment has the potential to become a technological alternative to improve
66 storage of fruit and vegetables.

67 1-Methylcyclopropene (1-MCP) is an ethylene antagonist that widely used in
68 many horticultural industries (Blankenship & Dole, 2003). 1-MCP has been shown to
69 extend shelf-life, through fruit firmness maintenance, delaying carotenoid accumulation,
70 reducing respiration rate and ethylene production (Blankenship & Dole, 2003, and Cliff et
71 al., 2009). 1-MCP has been shown to be very effective in delaying ripening and in
72 extending the shelf life of tomatoes (Wills & Ku, 2002). Noting that UV-C treatment
73 induces ethylene synthesis (Stevens et al., 1998), and that this hormone could interfere in
74 the responses to UV-C, treatment unit of 1-MCP was applied to evaluate the impact of
75 UV-C treatment without the influence of ethylene. Previous study observed the
76 application of combination UV-C and 1-MCP, followed by storage in air at room
77 temperature (Tiecher et al., 2013 and Severo et al., 2015), they reported that combination
78 treatment of UV-C and 1-MCP delayed the tomato fruit degreening.

79 Ethylene is a ubiquitous in the storage environment (Wills et al., 2000), where the
80 ethylene levels in the supermarkets have been shown to be 0.017-0.035 $\mu l\ l^{-1}$ and greater
81 than 0.06 $\mu l\ l^{-1}$ in the wholesale markets and distribution centres. To date, there have
82 been no studies on UV-C treatments and in combination with 1-MCP followed by storage
83 in continuous low level ethylene atmosphere. Therefore, the objective of this study was to
84 evaluate the effect of UV-C treatment in combination with 1-MCP on tomato quality
85 during storage at 20°C with 100% RH, in continuous air containing 0.1 $\mu l\ l^{-1}$ ethylene.

86 **Materials and methods**

Produce

Mature green or when fruits started to show the changed in incipient pink colouration at the end of blossom tomatoes (*Solanum lypopersicum cv* Neang Pich) were harvested from NSW Department of Primary Industries greenhouse (Ourimbah, N.S.W, Australia). Fruits were hand-harvested from greenhouses in the cool of early morning to minimise temperature differences at harvest. Tomatoes of uniform shape and size were taken to the laboratory, weighed, randomised and sorted into experimental units of 20 fruits.

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 tomatoes were placed approximately 15 cm from the UV-C light sources on one side then rotated 180°C and exposed again to ensure complete coverage; and during 12 min treatment received 13.6 kJm^{-2} of radiation. UV-C irradiation treatment was carried out at room temperature (20 ± 1°C) and relative humidity at 79%, unless otherwise stated.

In order to block the ethylene action, 0.5 $\mu l\ l^{-1}$ 1-MCP was applied in a 60 l sealed jar 24 h at 20°C and 85% RH, using SmartFresh powder (AgroFresh Solutions Inc., Philadelphia, PA, USA) containing 0.34% 1-MCP as active ingredient. Treatments

consisted of fruit without UV-C or 1-MCP application (control), UV-C application at 13.6 kJm^{-2}, 0.5 $\mu l\ l^{-1}$ 1-MCP and a combined 1-MCP + UV-C application under the same conditions as when applied separately. For the combined treatment, UV-C was applied 24 h after the 1-MCP application. This unit treatment was performed to evaluate the effect of UV-C treatment without the interference of ethylene. After treatment, all fruit were stored in a constant atmosphere of 0.1 $\mu l\ l^{-1}$ ethylene to provide simulated storage conditions at 20°C and 100% RH. Treatment unit was 20 tomato fruits.

Determination of fruits quality attributes

Tomato quality (every day or every second day) was measured weight loss, ethylene production, respiration rate, and skin colour. Tomatoes were also assessed for firmness, soluble solids content (SSC) and titratable acidity (TA) when fully ripe. The chlorophyll, lycopene, total phenols and total antioxidant were analysed at the beginning of the experiment (day 0) and when tomatoes were fully ripe. The weight loss percentages were calculated based on the initial weight of the tomatoes.

The colour was assessed according to the method of Tiecher et al. (2013). Specifically, skin colour was measured by Hue angle using a Minolta colorimeter (Minolta CR-400, Osaka), where the average of 3 points from calyx to blossom end were measured. Hue angle (°Hue) was calculated using the formula °Hue = arctan (b*/a*). The ethylene production and respiration were measured according to Pristijono (2007), where tomatoes were transferred to a sealed 750 ml glass jars at 20°C, and after one hour 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). The ethylene concentration was

133 calculated with reference to the concentration of an ethylene standard. Ethylene
134 production was calculated as [(C_2H_4 (µl l^{-1}) x volume (ml)) / (weight (kg) x Time (h))],
135 and expressed as µl $C_2H_4.kg^{-1}.h^{-1}$. Carbon dioxide concentration was measured to within
136 0.1% using an ICA40 series low volume gas analysis system (International controlled
137 Atmosphere Ltd., Kent, UK). Respiration rate was calculated as [(CO_2 (%) x volume
138 (ml)) / (weight (kg) x Time (h) x 100)] and expressed as ml $CO_2.kg^{-1}.h^{-1}$.
139 Tomato firmness was determined as the maximum force (Lloyd texture analyser,
140 Fareman, UK), required to push a 7 mm probe into the fruit flesh to a depth of 2 mm. The
141 average of 2 reading points from each side of the fruit was taken. Results were expressed
142 in Newton (N). The soluble solid content (SSC), expressed as °Brix, was measured
143 according to Pataro et al. (2015), with slight modifications where sample were collected
144 from the pressed juice of fruit by means of a hand refractometer (ATAGO Inc., Bellevue,
145 WA, USA). Titratable acidity (TA), expressed as % citric acid, was determined by
146 titrating 3 ml tomato supernatant to pH 8.2 with a 0.1 N NaOH solution using an
147 automatic titrator (Mettler Toledo T50, Switzerland).

148 ***Chemical analysis and antioxidant activity evaluation***

149 Three tomatoes were randomly selected from each treatment units, at the beginning of the
150 experiment and after each fruit was fully ripe. After sampling, tomatoes were sliced into
151 small pieces discarding the top and bottom sections and immediately stored at −20°C
152 until further analysis. The frozen samples were later analysed for chlorophyll, lycopene
153 content, total phenolic content and total antioxidant activity.

154 *Total chlorophyll and lycopene content*

Total chlorophylls and lycopene were estimated according to the method of Lichtenthaler and Wellburn (1983). Specifically, 1 g of blended sample was mixed with 10 ml 100% acetone in test tubes and held at -20^{o}C for 48 h. The samples were then vortexed, centrifuged at 10,000 × rpm for 10 min at 20^{o}C and then the supernatants were filtered through Whatman No 1 filter in volumetric flasks of 25 ml. Subsequently, 10 ml 100% acetone were added to the precipitate and the samples were shaken at 150 × rpm for 10 min. The samples were again filtered and added at the previous volumetric flasks, which were completed with 100% acetone and the absorption was determined spectrophotometrically at 652 nm. The following formula was used for the calculation of total chlorophyll and lycopene based on the study by Arnon (1949); Total chlorophyll (mg l^{-1}) = D652 × 1000/34.5, where D652 is the absorbance at 652 nm and 34.5 is the value of the specific absorption coefficient at 652 nm. The following formula was used for the calculation of lycopene; Lycopene: (mg g^{-1}) = (Abs 503 x Volume (ml)) x 3.1212 / Weight (g)). Where A503 the absorbance at 503 nm and 3.12 is the extinction coefficient.

Total phenolic content

The total phenolic content was measured by the Folin–Ciocalteu method as described by Singleton and Rossi (1965) and the results were expressed as mg gallic acid equivalents (GAE) per 100 g of fresh weight (mg GAE 100^{-1} g FW).

Total antioxidant activity

DPPH radical scavenging activity was determined according to Brand-Williams et al. (1995), with slight modifications. Specifically, 200 μl of the extracted sample were added

to 2800 µl 100 µm 2,2-diphenyl-1- picrylhydrazyl (DPPH) methanolic solution, it was vortexed and maintained in dark and at 20°C for 1 h. Absorbance was measured at 517 nm. The percentage of DPPH˙ scavenging is calculated according to the equation of % DPPH scavenging = 100 × (control absorbance – sample absorbance / control absorbance).

Statistical analysis

The experimental design was completely randomized, consisting three UV-C treatment units (a) control (without UV-C or 1-MCP), (b) UV-C, (c) 1-MCP and (d) UV-C + 1-MCP. The experiments were replicated three times. The one-way ANOVA and the Least Significance Difference (LSD) were conducted using the SPSS statistical software version 22. Data were reported as means ± standard deviations. Differences between the mean levels of the components in the different treatments were taken to be statistically significant at $p < 0.05$.

Results and discussion

Tomatoes at the mature green stage or when the fruits had just started to show incipient pink colouration at the end of blossom tomatoes stage were used since this represents the stage at which they are usually harvested in order to minimize loss during transport and storage. Skin colour values determined before each of the three replicate experiments showed only slight differences among the three batches used. Hue angle (°Hue) is one of the appropriate ripening indexes in tomato (Lopez Camelo & Gomez, 2004) and the results did not show significant differences ($p < 0.05$) between batches denoting homogeneity in terms of maturity level. Not surprisingly, the average initial lycopene

199 content (mg/g f.w) was low and high in chlorophyll content (mg l^{-1}). Ethylene
200 production, respiration rate, SSC, TA, fruit firmness, total phenolic content and
201 antioxidant activity of tomatoes at harvest is presented in Table 1.

202 ***Effect on weight loss***

203 Weight loss of tomatoes was measured when the fruits were fully ripe (°Hue = 60.4), and
204 with the results showing that the tomatoes treated with UV-C alone did not significantly
205 affect weight loss during ripening (Figure 1A). The 1-MCP treatment and combined
206 treatment of 1-MCP + UV-C fruits showed a significantly ($p < 0.05$) lower in weight loss
207 than UV-C treatments or control fruits, however the weight loss was only 0.2 % lower
208 compared to control fruits and not to be considered commercially significant. This result
209 contrary to Pinheiro at al., (2015) who found that tomatoes treated with 4.83 kJm^{-2} UV-C
210 showed lower levels of weight loss of fruits after 15 d storage at 10ºC, than untreated
211 UV-C fruits. The difference observed may be due to the storage conditions, where in this
212 study, after treatments the fruits were stored in air containing 0.1 $\mu l\ l^{-1}$ ethylene at 20°C,
213 with 100% RH until the fruits were fully ripe.

214 ***Effect on ethylene production***

215 Tomato is a climacteric fruit that is characterised by increased ethylene production and
216 continued ripening after harvest (Cara & Giovannoni, 2008). The results of this
217 experiment showed that UV-C, 1-MCP and 1-MCP+UV-C treatments slowed ethylene
218 production, while control fruit had concluded the ethylene climacteric peak in 6 d, the
219 UV-C or 1-MCP or 1-MCP+UV-C treated fruit after 6 d storage still had elevated
220 ethylene production which indicated that fruit were not completely ripe (Figure 2A). In

addition, the maximum climacteric peak was delayed by 3 d with UV-C or 15 d with 1-MCP treatments. The combination treatment of 1-MCP prior to UV-C was able to delay the climacteric by 12 d which explained that the application of 1-MCP prior to UV-C was unable to promote ethylene production. These results also show that the UV-C treatment delayed ripening in tomatoes by inhibiting ethylene production during storage. These results in accord with the privious report by Tiecher et al. (2013) who found that tomatoes treated with 3.7 6 kJm^{-2} still had elevated ethylene production after 7 d storage in air. The delay in ethylene production also affected the development of the red colour where untreated tomato fruit changed colour quicker than fruit treated with UV-C, 1-MCP or 1-MCP +UV-C. It should be noted that in this experiment the storage environment contained 0.1 $\mu L.L^{-1}$ ethylene to stimulate comercial storage conditions. These results are consitent with those previously reported by Stevens et al. (1998) and Maharaj et al. (1999) observed a reduction of ethylene production in tomatoes treated with UV-C. These results suggest that the UV-C treatment irradiation extends the postharvest life of tomatoes by delaying the peak ethylene production and fruit ripening.

Effect on skin colour

The most visible symptom of tomato ripening is the change in skin colour from green to red, where the Hue value of a typical tomato fruit will decrease as the ripening process progresses (Jagadeesh et al. 2011). Tomato colour (Hue values) changed during storage are shown in Figure 2B, where at day 0, all samples were described as green colour (high Hue values). The tomatoes treated with 13.6 kJm^{-2} UV-C alone or 0.5 $\mu l\ l^{-1}$ 1-MCP alone or the combination of 13.6 kJm^{-2} UV-C and 0.5 $\mu l\ l^{-1}$ 1-MCP produced significant delays in colour change. Untreated fruits fully ripened and became red 6 d after harvest while

UV-C treated fruit became fully red 11 d after harvest, whilst fruits from the combined treatment of 1-MCP + UV-C, became fully red within 17 d after harvest. As expected, 1-MCP treated fruits were the longest period to become fully red within 21 d. Even though, there was difference in the storage conditions with previous study, where the fruit was stored in air at room temperature, but this result was consistent with the finding by Tiecher et al. (2013) and Severo et al. (2015) who reported that the application 3.7 kJm^{-2} UV-C maintained the green colour of tomatoes, and combination treatment of 2 $\mu L.L^{-1}$ 1-MCP and 3.7 kJm^{-2} UV-C further inhibit colour change, and retained a higher hue values. Also, Liu et al. (2009) observed that after tomato treated with 13.7 kJm^{-2} UV-C, followed by storage in air with fans continuously circulating air across the tomatoes, they found that a high Hue value was obtained on UV-C treated fruits after 21 d storage at 14°C. This result suggests that UV-C treatment alone or in combination with 1-MCP delayed the tomato degreening regardless the storage conditions.

Effect on firmness

Fruit firmness was evaluated when the tomatoes were fully ripe (6 d for control, 11 d for UV-C treated, 17 d for 1-MCP+UV-C treated and 21 d for 1-MCP treated fruits). The results showed that the highest firmness was maintained in the combined treatment of 1-MCP + UV-C treated fruit followed by 1-MCP alone, UV-C alone and untreated fruit (Figure 1B). The UV-C treatment did not contribute to flesh firmness preservation. However, combining 1-MCP and UV-C treatments produced significantly firmer fruits than UV-C treatment alone or when compared to control. This result confirms that 1-MCP treatment contributed to maintaining flesh firmness in tomato (Jeong et al., 2002). Moreover, comparing untreated and UV-C treated fruits, there was no significant in fruit

267 firmness ($p < 0.05$). These results were contradictory with the previous report of Barka et
268 al., (2000) and Stevens et al., (2004) who reported that tomato firmness was significantly
269 increased by low-dose UV-C treatment, and that cell-wall degrading enzyme activities
270 were also decreased. Also, Liu et al. (2009) reported that tomato firmness was
271 significantly decreased by UV-C treatment. This experiment result suggest that UV-C
272 treatment acts more in colour (degreening and reddening) than in firmness changes of
273 tomatoes.

274 ***Effect on TSS, TA and TSS/TA ratio***

275 SSC and TA were measured on fully ripe fruits and the result shows that SSC and TA
276 were not affected by UV-C, 1-MCP treatments alone or the combination treatment of 1-
277 MCP + UV-C (Table 2). These results are consistent with those previously reported by
278 Liu et al., (2009) who observed that SSC did not change in tomatoes (cv Red Ruby) after
279 treatment with 22.8 $W.m^{-2}$ UV-C lights stored at 12 - 14°C for 21 d. However, other
280 reports have shown that tomatoes treated with 3.7 $kJ.m^{-2}$ UV-C followed by storage at
281 15°C for 15 d produced lower sugar content and higher in TA that untreated fruits
282 (Charles et al., 2016). These differences may be due to the assessment of sugar content,
283 where in this experiment SSC and TA were measured, while the previous report
284 measured the total simple sugar of glucose, fructose and sucrose, as well as total organic
285 acid were measured.

286 The SSC/TA, or sugar to acid ratio is an important taste factor and an indicator of
287 maturity, ripeness, or both in some mature fruit-type vegetables such as tomato (Malundo
288 et al., 1995). Loss of sensory quality in tomatoes is associated with reduction of sweetness
289 and acidic taste (Grierson & Kader, 1986). In this experiment, the SSC/TA showed no

290 significant difference between untreated fruits and all other treaments (Table 2). These
291 results suggest that UV-C treatments, alone or in combination with 1-MCP, did not have
292 any effect on SSC to TA ratio in tomato.

293 ***Effect on total chlorophyll and lycopene content***

294 Colour change in fruit which including chlorophyll degradation is closely associated with
295 the chloroplast transition to chloroplast, which regulated by ethylene (Barsan et al., 2010).
296 In this study, Total chlorophyll content was measured when tomatoes were fully ripe. The
297 result shows that there were not statistically different in total chlorophyll content between
298 treated and untreated fruits (Figure 3A). However untreated tomatoes showed higher
299 chlorophyll content than UV-C treated fruits, which potentially UV-C treatments induced
300 chlorophyll degradation, and when comparing UV-C treatments and 1-MCP treatment
301 alone or the combination treatment of 1-MCP + UV-C show that UV-C treated fruits had
302 lower chlorophyll content than fruits treated with combination of 1-MCP + UV-C or 1-
303 MCP alone. This may suggest that 1-MCP prevented chlorophyll degradation during
304 ripening, which may also indicate that chlorophyll degradation is ethylene dependent.
305 Lycopene, is the major carotenoid present in the tomato fruit and is one of the
306 most important health attributes of tomatoes. The accumulation of lycopene during the
307 ripening process causes an increase in the redness of tomatoes (Li et al., 2016). In these
308 observations, after ripening at 20ºC, all tomatoes were measured the lycopene content,
309 and the results show that there was no significant difference between untreated tomatoes
310 and all other treated fruits (Figure 3B). Moreover, the fruits treated with UV-C had
311 significantly higher lycopene content than 1-MCP treated fruits or combination treatment
312 of 1-MCP +UVC, and these results suggest that lycopene accumulation maybe partially

313 ethylene dependent, as even though UV-C treated fruits had low ethylene production
314 (2.66 μL $C_2H_4.kg^{-1}.h^{-1}$) but accumulated high lycopene content (35.1 mg/g f.w.). The
315 difference in lycopene content was potentially due to weight loss since the high lycopene
316 content was found in tomatoes with high weight loss (Figure 1A).
317 These results are in an agreement with the data reported by Tiecher et al., (2013)
318 who found that 1 -MCP treatment inhibited total carotenoid accumulation including
319 lycopene. The increased lycopene content may be attributed to a pressure-induced
320 physiological stress during storage. Gonzalez-Aguilar et al. (2010) suggest that
321 postharvest treatments used to prolong fruit shelf-life such as high O_2 atmosphere,
322 irradiation, and heat treatments could induce changes in metabolic activity of the treated
323 produce, such as the triggering bioactive molecule synthesis. UV-C treatment during
324 storage may act in a similar manner.

325 ***Effect on total phenolic content (TPC)***

326 After ripening of tomatoes in air containing 0.1 $\mu l\ l^{-1}$ ethylene at 20°C and 100% RH, the
327 total phenolic content was measured and the results showed that untreated tomatoes had
328 significantly lower TPC compared to other treatments (Figure 4A). The highest TPC was
329 found in the combination treatment of 1-MCP and UV-C, followed by fruits treated with
330 UV-C, 1-MCP alone, with an increase of 12%, 12% and 24% for UV-C, 1-MCP and 1-
331 MCP +UV-C treatments, respectively compared with the control.
332 These observations are consistent with those previously reported by Liu et al.,
333 (2011) who found that tomatoes treated with UV-C had highest levels of TPC. This
334 maybe due to general abiotic stresses which affect the pathways involved in biosynthesis
335 of the main three groups of secondary metabolites including terpenes, phenolic, and

336 nitrogen-containing compounds (Cisneros-Zevallos, 2003). Many studies have reported
337 the enhancement of phenolic compound contents by environmental stress. For example,
338 UV-C irradiation has been demonstrated to increase the levels of phenolics in several
339 fruits such as tomato (Jagadeesh et al., 2011), apple (Dong et al., 1995), mango
340 (González-Aguilar et al., 2007), and grape (Cantos et al., 2002). This may be a result of
341 plant tissue induction of protective pathways to produce an accumulation of UV-light-
342 absorbing flavonoids and other phenolics. In this study, 13.6 kJm^{-2} UV-C treatment was
343 found to enhance total phenolic content when the fruits were fully ripe, the further
344 significant enhancement was found in icombined 3.6 kJm^{-2} UV-C and 0.5 $\mu l\ l^{-1}$ 1-MCP
345 treated fruits.

346 ***Effect on total antioxidant activity***

347 After fruit ripening at 20ºC, the DPPH antioxidant activity of fully ripe tomatoes was
348 measured and the result is presented in Figure 4B. The result shows that there was no
349 significant difference in DPPH activity between treated fruit and control. The main
350 antioxidants in tomato are carotenoids, ascorbic acid, and phenolic compounds
351 (Giovanelli et al., 1999). In this study, a 13.6 kJm^{-2} UV-C, 0.5 $\mu l\ l^{-1}$ 1-MCP and
352 combination treatment of 0.5 $\mu l\ l^{-1}$ 1-MCP and 13.6 kJm^{-2} UV-C did not significantly
353 affect DPPH scavenging activity during ripening periods even though the lycopene
354 content was found to be higher by 11% in UV-C treated fruits than control. The
355 relationship between lycopene and antioxidant activity is not always directly proportional,
356 where the increase in lycopene content does not necessarily result in an increased
357 antioxidant activity. In certain cases, an inverse relationship between antioxidant activity
358 and lycopene content of red tomato varieties was observed at the end of the ripening stage

(Kotíková et al., 2011). The assessment of the single antioxidant assay indicated that an increase in pure lycopene concentrations beyond critical levels could reduce scavenging capacity values (Liu et al., 2008). However, its interactions with such other antioxidants such as β-carotene, lutein, α-tocopherols could act either additively, synergistically or antagonistically in scavenging free radicals (Zanfini et al., 2010).

Conclusions

The quality of fully ripe tomatoes was evaluated after the application of 13.6 kJm^{-2} UV-C or 0.5 $\mu l\ l^{-1}$ 1-MCP alone or the combination of 0.5 $\mu l\ l^{-1}$ 1-MCP and 13.6 kJm^{-2} UV-C followed by storage in air containing 0.1 $\mu l\ l^{-1}$ ethylene at 20°C. Fruit ripening was delayed by 3 d with UV-C treatment and further delayed when the application of 1-MCP added. The combination treatment of 1-MCP and UV-C resulted in firmer fruits compared to untreated fruits and UV-C or 1-MCP treated fruit alone. The level of TPC was significantly affected by combination treatment of 1-MCP and UV-C, whereas there was no difference in DPPH antioxidant activity. The ratio SSC to TA was not affected by the treatments. Overall, the UV-C treatment combined with 1-MCP improved tomato quality by delayed the fruits ripening and improved the firmness, as well as TPC. More study is required to assess the effect of application of UV-C followed by 1-MCP, to determine if the mode of action of UV-C is similar with this study.

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Table 1. Quality parameters of tomatoes at the beginning of the experiment. Values represent the mean and standard error (S.E.) of three replicates consisting of 10 tomatoes each replicate.

Parameter	Value
Colour (°Hue)	116.0 ± 0.2
Ethylene (µl $C_2H_4.kg^{-1}.h^{-1}$)	0.17 ± 0.07
Respiration rate (ml $CO_2.kg^{-1}.h^{-1}$)	5.11 ± 0.26
SSC (°Bx)	4.2 ± 0.2
TA (% citric acid)	1.02 ±0 .08
Ratio TSS to TA	4.2 ± 0.2
Firmness (N)	42.9 ± 0.8
Chlorophyll (mg/L)	0.46 ± 0.03
Lycopene (mg/g f.w)	1.27 ± 0.06
TPC (mg Gallic acid equiv /g f.w)	0.62 ± 0.02
Total antioxidant activity (% DPPH scavenging activity)	18.2 ± 1.3

Table 2. Soluble solids content (SSC), titratable acidity (TA), and SSC/TA (or sugar/acid) ratio of fully ripe tomato after treated with UV-C, 1-MCP and UV-C combined with 1-MCP, followed by storage in in continuous air containing 0.1 μl l^{-1} ethylene at 20°C.

Treatments	SSC (°Brix)	TA (% citric acid)	SSC/TA ratio
Control	4.1	0.51	8.1
UV-C	3.9	0.50	7.9
1-MCP	3.9	0.50	7.8
1-MCP + UV-C	4.0	0.50	8.1
LSD (5%)	± 0.4	± 0.11	± 0.4

Values are the mean of 3 replicates

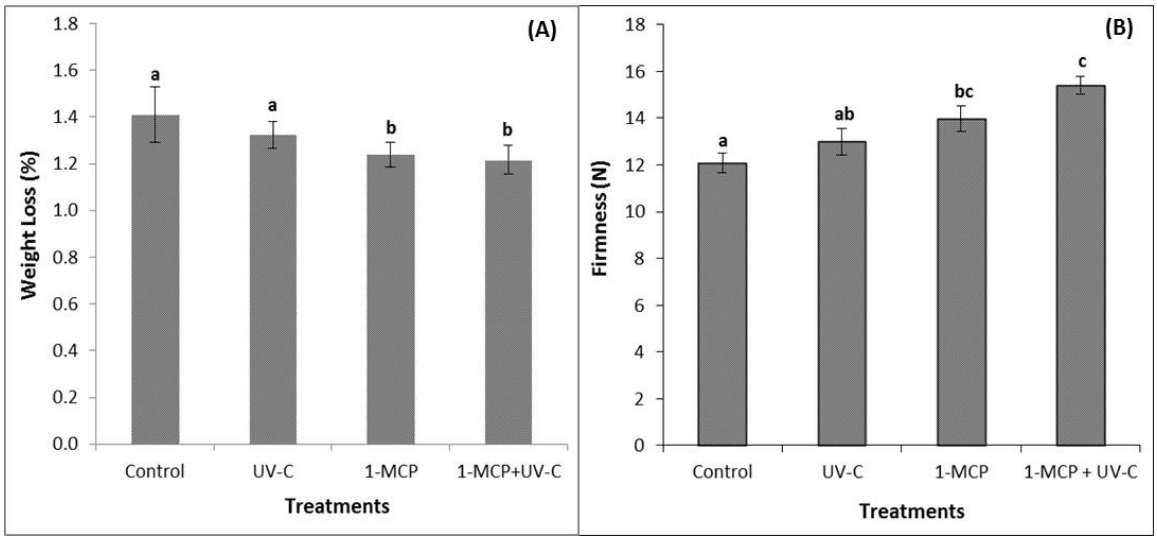

Figure 1. Weight loss (A) and firmness (B) of tomato after treated with UVC, 1-MCP and UV-C integrated with 1-MCP, followed by storage in continuous air containing 0.1 $\mu l.l^{-1}$ ethylene at 20°C.

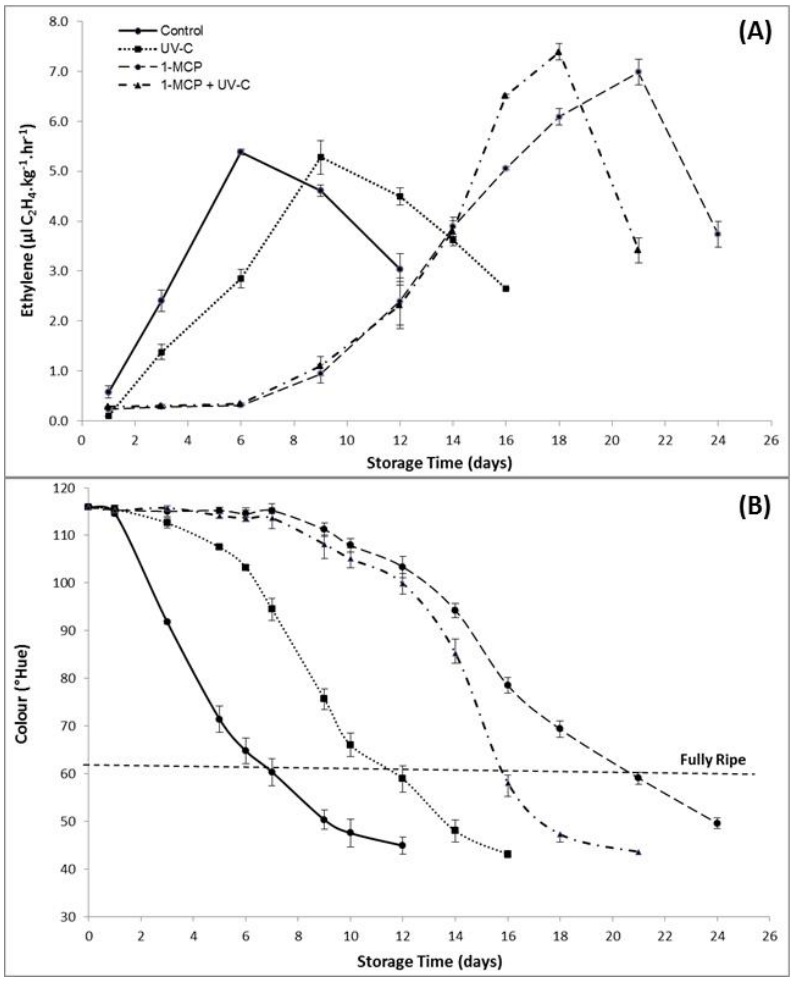

Figure 2. Ethylene production (A) and skin colour (B) of tomato after treated with UV-C, 1-MCP and UV-C combined with 1-MCP, followed by storage in continuous air containing 0.1 µl l^{-1} ethylene at 20°C.

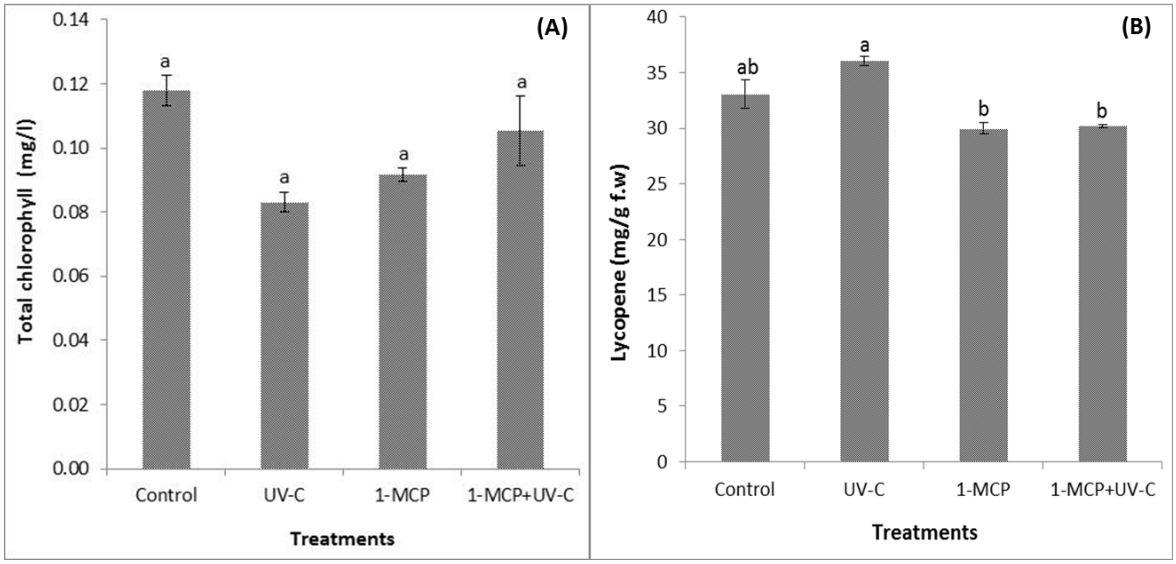

Figure 3. Total chlorophyll (A) and lycopene content (B) of fully ripe tomato after treated with UV-C, 1-MCP and UV-C combined with 1-MCP, followed by storage in continuous air containing 0.1 µl l^{-1} ethylene at 20°C.

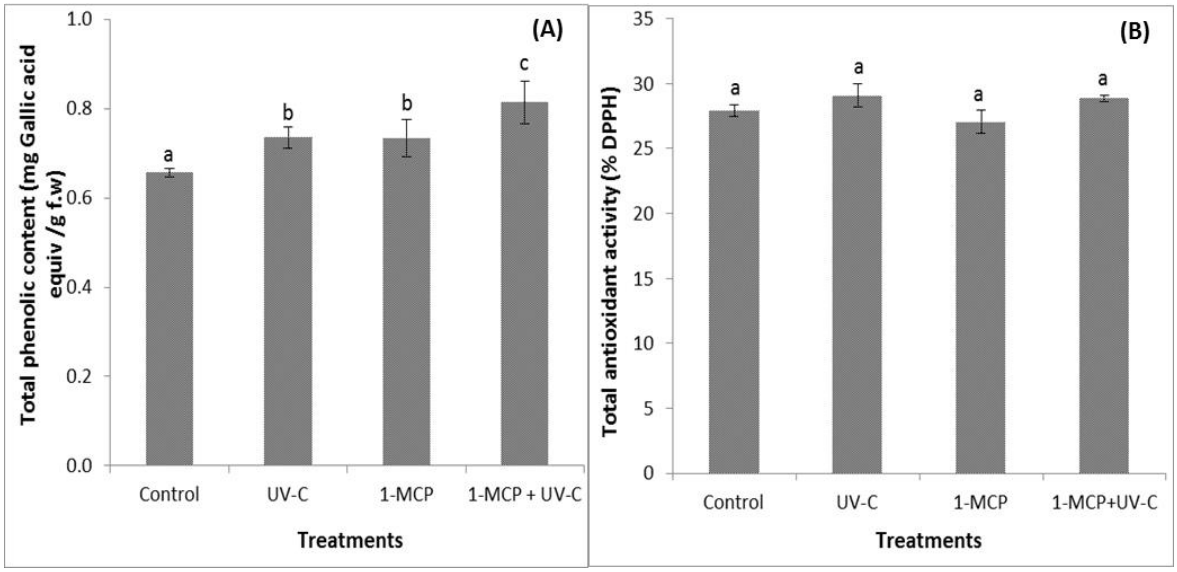

Figure 4. Total phenolic content (A) and total antioxidant activity (B) of fully ripe tomato after treated with UV-C, 1-MCP and UV-C combined with 1-MCP, followed by storage in continuous air containing 0.1 µl l^{-1} ethylene at 20°C.