International Journal of Technical Research and Applications e-ISSN: 2320-8163,
www.ijtra.com Volume-2, Special Issue 5 (Nov-Dec 2014), PP. 07-10

ENHANCEMENT OF LYCOPENE AND B-CAROTENE PRODUCTION IN CHERRY TOMATO FRUITS (*SOLANUM LYCOPERSICUM* L. VAR. CERASIFORME) BY USING RED AND BLUE LIGHT TREATMENT

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***Abstract*— Cherry tomatoes, *Solanum lycopersicum* var. cerasiforme, are known as sources of antioxidants, which are beneficial to prevent several diseases such as cancer, cardiovascular, etc. Lycopene and β-carotene, natural red and orange pigment, are the major carotenoid antioxidants in tomato fruits. The synthesis of lycopene and β-carotene is a light-regulated reaction, which mediated by phytochrome and cryptochrome. The aims of this study were to determine the optimal spectrum of light to enhance lycopene, β-carotene, and sugar production, and to evaluate the efficiency of the antioxidants production. Red (663 nm), blue (470 nm), and white light treatment were given to tomato plants at the beginning of flowering stage for 3 hours after darkness. The result of this study showed that the white light treatment induced the best vegetative biomass growth (μ = 0.072 day-1), while red light treatment enhanced fruit biomass yield (1.15 fold), lycopene (35.8%), β-carotene (46.5%) and sugar content (27.5%). In contrast, the same effect was not observed in plants treated with blue and white light. The efficiency of red light treatment in this system was 2.65 MJ/g lycopene increment and 7.45 MJ/g β-carotene increment.**

***Key words*— β-carotene, cherry tomato, lycopene, mass distribution, sugar**

I. INTRODUCTION

Cherry tomato (*Solanum lycopersicum* L. var. cerasiforme) is one of global major horticultural commodities. It is one of dietary source of antioxidants, since the fruit contains lycopene (>100 mg/kg fw) and β-carotene (>35 mg/kg fw) [1,2]. Lycopene and β-carotene are natural red and orange carotenoid pigments which are synthesized and accumulated during the fruit development and ripening [3]. Lycopene are beneficial to prevent health problems such as cancer, cardiovascular disorder, stroke, etc. [4], while β-carotene is dietary provitamin A which is readily absorbed by the body to synthesize vitamin A. Therefore, lycopene and β-carotene become high-economic-value commodity.

Schofield & Paliyath [5] stated that red light exposure increased the activity of phytoene synthase (PSY), the key enzyme of carotenoid biosynthesis, through phytochrome-mediated mechanism. On the other hand, according to Giliberto et al. [6], blue light through cryptochrome-mediated reaction altered the formation of lycopene and β-carotene by repressing the activity of lycopene β-cyclase (LCYB), which converts lycopene to β-carotene. Therefore, both of red and blue light spectrums affect the production of lycopene and β-carotene [7].

Kondo et al. [8] reported that exposure of red and blue light to grape plants during three hours after sunset and three hours before sunrise increased endogenous abscisic acid (ABA) at the skin of grape fruits. ABA is synthesized through the same metabolic pathway as carotenogenesis. Red and blue light treatment did not only induce ABA, but also increased sugar content of grape fruits. It was suggested that the exposure of red and blue light increased the activity of key enzymes in the formation of sucrose, i.e. invertase, sucrose synthase, and sucrose phosphate synthase [8].

There is no information related to enhancement of lycopene and β-carotene in tomato fruit by using light treatment. Therefore, the aims of this study were to determine the optimal light spectrum to enhance lycopene, β-carotene and sugar production in cherry tomato fruits; to construct mass distribution of lycopene, β-carotene and sugar production treated with red, white and blue light exposure; also to evaluate exposure of red, light and blue light on lycopene and β-carotene synthesis in cherry tomatoes.

II. MATERIALS AND METHODS

A. Materials

Materials of this study were one month old cherry tomato *Solanum lycopersicum* var. cerasiforme plants, at the beginning of flowering stage.

B. Maintenance and light treatments on cherry tomato plants

Cherry tomato plants were exposed to direct sunlight in the morning until noon, watered as much as 600 mL / polybag every 2 days, and fertilized with NPK fertilizer (20:15:15) at a concentration of 20 g/L of 600 mL every 9 days.

Light treatments were given to plants based on modified Kondo *et al.* method [9], i.e. plants were exposed to red (663 nm, 1 W), white (1W) and blue (470 nm, 1 W) LED light for 3 hours after darkness. Control of this treatment was plants which were not exposed to light during night.

Plants cultivation and treatment were conducted until the plants reached the harvesting stage (2 months old). Harvesting was done every 7 days for 28 days treatments.

C. Growth kinetic of cherry tomato plant

Dry weight of vegetative biomass of tomato plants was measured on day 0 and day 28. Based on the acquired data, growth curves were plot and plant growth kinetic parameters, such as specific growth rate and doubling time,

were calculated.

Growth biomass parameter based on the first order of exponential growth (Eq. 1) and doubling time equations (Eq. 2) according to Shuler and Kargi [9]:

$$\frac{dX}{dt} = \mu_{net} X;\ \mu = \frac{\ln X - \ln X_0}{t} \quad (1)$$

$$d.t. = \frac{\ln 2}{\mu} \quad (2)$$

D. Lycopene, β-carotene and sugar content analysis

Harvested cherry tomatoes were homogenized. Homogenate were then separated for sugar and carotenoid analysis. Sugar content analysis was measured by Brix refractometry method. Carotenoid analysis was conducted based on modified Sadler *et al.* extraction method [10]. One gram homogenate was extracted by 100 mL solvent of n-hexane:acetone:ethanol (2:1:1), incubated for 24 hours. Then, 15 mL of distilled water was added to the extract to separate the nonpolar phase (top) from polar phase (bottom). Absorbance of nonpolar phase was measured at a wavelength of 451 nm and 503 nm by method of Fish with n-hexane as blank [11].

III. Result and Discussion

A. Vegetative biomass growth

Figure 1 showed the growth kinetics of vegetative biomass. Plants treated with white light showed the highest vegetative biomass growth, with specific growth rate of 0.072 day^{-1}, then followed by plants treated with blue light (μ = 0.068 day^{-1}), red light (μ = 0.064 day^{-1}) and control plant (μ = 0.057 day^{-1}, Fig 1). White light as polychromatic light, composed of broad spectrum of light including red and blue light which are the most efficient spectrums absorbed by chlorophyll in photosynthesis. Thus, white light treatment might support photosynthesis process better compared to other treatment.

B. Fruit biomass yield

Figure 2 described the total fruit biomass harvested after 28 days of treatment. Tomato plants treated with red light showed the highest harvest yield (630 grams) compared to that in other treatments, with 14.5% increment from control. It supported the fact that fruit sets production was initiated by flower development, which was regulated by phytochrome-mediated reaction [12]. However, Giliberto et al. [6] reported that tomato plants with overexpression of Cry2, gene encoding for enzymes of cryptochrome synthesis, showed retardation in flowering. It was suspected that there was one or more spectrum in white light such as blue spectrum with antagonistic effect to flowering [6].

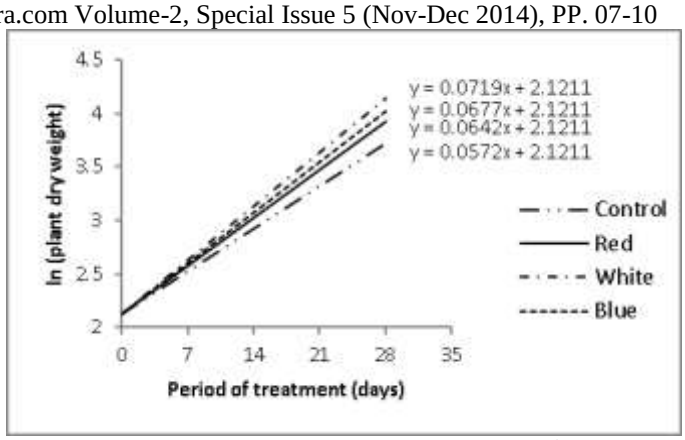

Fig. 1. Vegetative biomass growth kinetics. The gradient of the lines showed the value of specific growth rate, μ.

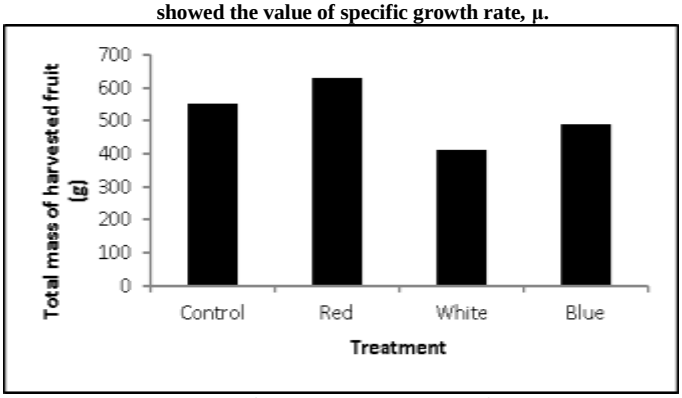

Fig. 2. Total harvested fruit biomass in 28 days after treatment.

C. Sugar content (Brix analysis)

Sugar content in tomato fruits was presented in Fig. 3, they ranged between 6 – 9.3 °Bx. Red light treatment enhanced sugar content in cherry tomato fruits. According to Vassey [13], red light regulated the activity of sucrose phosphate synthase (SPS), one of the key enzymes in sucrose synthesis, through phytochrome-mediated reaction.

TABLE I. MASS DISTRIBUTION OF BIOMASS FOR 28 DAYS TREATMENT

Treatment	Vegetative biomass (g)	Fruit biomass (g)	Total amount in fruit		
			Lycopene (mg)	β-carotene (mg)	Sugar (g)
Control	41.33	47.7	63.78	17.46	41.25
Red	50.28	55	86.62	25.58	52.61
White	62.43	41	40.17	15.68	30.55
Blue	55.54	45.9	52.43	16.93	36.26

D. Lycopene and β-carotene content

Lycopene and β-carotene content in cherry tomato fruits were described in Fig. 4. Lycopene content ranged from 83.2 to 172.9 mg/kg fresh weight, while β-carotene ranged from 29.4 to 45.7 mg/kg fresh weight. Analysis of the result showed that red light treatment enhanced lycopene and β-carotene content.

Treatment of red light increased the activity of carotenogenic enzymes, especially phytoene synthase enzyme (PSY) [5,7,8], which implicated to the increase of metabolic flux toward the synthesis of lycopene and β-carotene. Blue light and white light treatment did not show the same result as Giliberto et al. [6], which reported the increase of lycopene content. It was believed that blue light spectrum repressed the activity of other carotenogenic enzymes.

E. Mass distribution

Table 1 described mass distribution construction based on result of 28 days of treatment. Mass flux of plants with white light treatment was directed to the formation of vegetative biomass, while red light treatment diverted the mass flux toward the formation of fruit biomass. The total amount of lycopene, β-carotene, and sugar was equal to the concentration of metabolites multiplied by total fruit biomass yielded. It was shown that red light treatment enhanced total amount of lycopene, β-carotene, and sugar up to 35.8%, 46.5%, and 27.5% respectively.

F. Energetic study

LED light energy of 60.5 kJ was the energy input of the system for 28 days. It was assumed that 5% of total light energy input was absorbed by plants [14]. Red light treatment increased amount of lycopene and β-carotene for 22.84 and 8.12 mg respectively. Thus, light energy of 2.65 MJ and 7.45 MJ were needed to increase the amount of lycopene and β-carotene for each 1 gram of metabolites.

IV. CONCLUSION

Red light treatment enhanced lycopene, β-carotene, and sugar production in cherry tomato fruits, with increment of 35.8%, 46.5%, and 27.5% respectively. The highest vegetative growth was achieved on tomato plants treated with white light, while the highest yield of fruit, sugar, lycopene, and β-carotene were achieved on plants treated with red light. The usage of red light energy to increase 1 gram of lycopene and β-carotene were 2.65 MJ and 7.45 MJ.

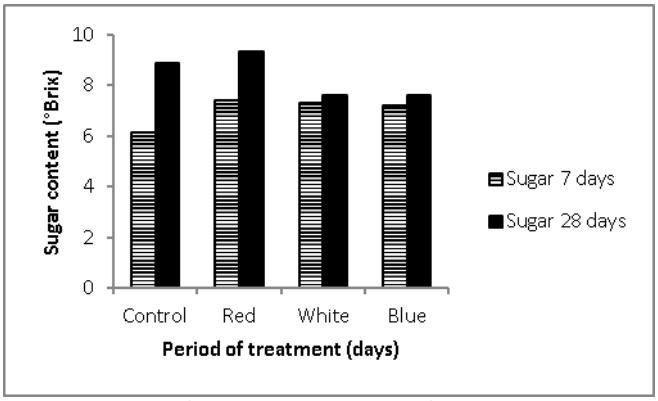

Fig. 3. Brix index of harvested cherry tomato fruits in each treatment. 1 °Brix ≅ 1 g sucrose in 100 g solution.

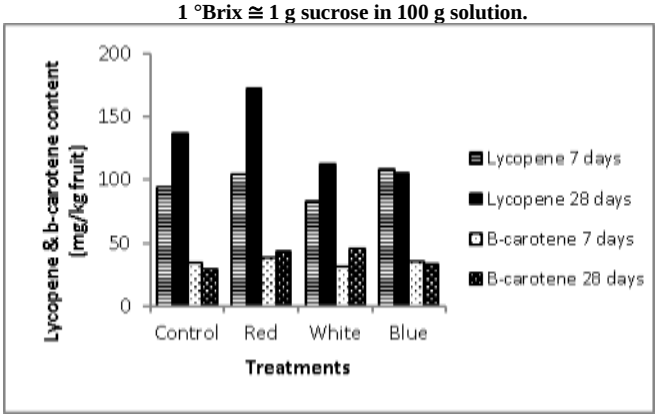

Fig. 4. Lycopene and β-carotene content of harvested fruit.

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