INFLUENCE OF LIGHT WAVELENGTHS ON GROWTH OF TOMATO

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Abstrak

Telah dilakukan penelitian tentang pengaruh panjang gelombang cahaya terhadap laju pertumbuhan dan karakteristik klorofil-a pada tanaman tomat. Panjang gelombang cahaya yang digunakan pada penelitian ini adalah 450 nm, 470 nm, 550 nm, 650 nm dan 680 nm dengan intensitas masing-masing 1000 lux. Penelitian dilakukan mulai saat pembibitan dari hari ke-0 sampai dengan hari ke-18 dan fase pertumbuhan dari hari ke-19 sampai dengan hari ke-53. Saat pembibitan, penyinaran dengan panjang gelombang 680 nm mempunyai laju pertumbuhan paling besar dibandingkan dengan panjang gelombang lainnya bahkan lebih besar dibandingkan dengan pembibitan dibawah sinar matahari (dialam bebas) khususnya pada hari ke-1 sampai dengan hari ke-8. Laju rata-rata pertumbuhan dengan penyinaran panjang gelombang ini sekitar 1,11 cm/hari. Sedangkan pada fase pertumbuhan penyinaran dengan panjang gelombang 680 nm tidak memberikan efek yang berarti, sebaliknya laju pertumbuhan paling besar pada fase ini terjadi pada penyinaran dengan panjang gelombang 650 nm. Kenyataan ini juga diperkuat dengan pengambilan data klorofil-a. Berdasarkan data yang diperoleh, laju pertumbuhan dan kadar klorofil-a dari penyinaran dengan panjang gelombang 650 nm masing-masing adalah 0,07 cm/hari dan 7,784 mg/L. Berdasarkan data-data pengamatan menunjukkan bahwa pertumbuhan tanaman tomat membutuhkan panjang gelombang berlainan yang merupakan fungsi waktu.

Kata kunci : *panjang gelombang cahaya; laju pertumbuhan; klorofil-a; tanaman tomat*

1. Background

Sunlight consists of about 4% ultraviolet radiation, 52% infrared radiation, and 44% visible light (Moore *et al*., 2003). The wavelengths of visible light lie from about 390 nm to 760 nm that is just a small section of the entire electromagnetic spectrum of solar radiation. Visible light corresponds roughly to the photosynthetically active radiation (PAR) from 400 nm to 700 nm (http://www.cropsreview.com/light-quality.html 2012). The light can be reflected, transmitted or absorbed. Only light that is absorbed can have an effect and the visible light that is reflected is the one that is perceived by the naked eye.

The wavelengths with primary importance in photobiology are ultraviolet (UV), visible light, and infrared (IR). According to Devlin (1975), the wavelengths between 300 nm to 900 nm are capable of affecting plant growth. However, it is not light quality alone that affects plant growth processes. Other properties of light including light intensity and light duration, also environmental factor such as time of the day, season, geographic location, atmospheric gases and moisture, clouds, smoke, dust, and other pollutants in the air, topography are involved.

Plants can synthesize food directly from inorganic compounds, known as autotroph. Plants use carbon dioxide and water to produce sugar and oxygen, necessary food through a process called photosynthesis. To conduct this process required the energy from sunlight.

Light directly influences plant growth by inducing photosynthesis and feeding plants energy. Plants are dependent on light to generate food, induce the growing cycle and allow for healthy development. Without light, natural or artificial, most plants would not be able to grow or reproduce, photosynthesis would not occur without the energy absorbed from sunlight and there would not be enough oxygen to support life.

Photosynthesis in plants can occur because of pigment of chlorophyll which is used to capture light.

Jones (2003) showed, total absorption of light by chlorophyll is not the same at all wavelengths due to chlorophyll contain several pigments. Urbonaviciute *et al*. (2007) showed that lettuce growth was better when illuminated with combined spectrum (one in red region, 650 nm and another in short-wavelength region, 500 nm, 460 nm or 365 nm) in respect to illumination using conventional lamps. Meanwhile, Tucker (1976) found that 5 minutes period far-red illumination immediately following a 16 h photoperiod from fluorescent tubes could completely suppressed side shoot growth in young tomato plants which made photosynthesis process more efficient. Other experiment on tomatoes conducted by Decoteau *et al.* (1991) found that treatments of tomatoes with red light generated a shorter transplant that produced more flowers earlier. There was no residual effect of this light treatment of tomato transplants on subsequent plant growth or fruit production. Based on the above descriptions, problems can be formulated of how each wavelengths of light affect the rate of growth and chlorophyll-a content of tomato plants. For the problems, there are necessary to do research on the precise light wavelength to chlorophyll-a photosynthesis process, thus increasing the rate of plant growth especially on vegetative phase. This study uses tomato plant which is short-life plant species and rapid harvest.

2. Basic Theory

Photosynthesis is a biochemical process by plants and algae to produce energy utilization (nutrition) by utilizing the light energy. The primary processes of photosynthesis, the conversion of electromagnetic energy (light) into chemical energy, are mediated by an integral membrane protein-pigment complex called the reaction center (RC) in which a sequence of photoinduced electron and proton-transfer reaction take place. Almost all living things depend on energy produced in photosynthesis. Photosynthesis is also producing most of the oxygen found in Earth's atmosphere. Photosynthesis is one way of the organism to assimilate carbon where carbon-free, CO_2, fixed into sugar as energy storage molecules. Another method is through chemosynthesis, which carried by number of bacteria. Photosynthetic reaction is as follows:

$$12H_2O + 6\,CO_2 + \text{light} \rightarrow C_6H_{12}O_6 + 6O_2 + 6\,H_2O \qquad (1)$$

Photosynthesis only takes place in cells which have photosynthetic pigments which called chlorophyll. Chlorophyll contains several pigments such as chlorophyll-a is particularly absorbing blue to violet (400-500 nm) and red light (650-700 nm) and chlorophyll-b, which absorb blue and orange light (600-650 nm). Chlorophyll-b reflects light yellow-green. Chlorophyll-a has direct role in the light reaction, while chlorophyll-b is not directly involved in light reaction (Govindjee and Braun, 1974). Schmid *et al.*, (2001) shown that, the absorption maxima of light-harvesting complexes (LHCs) between 645 and 660 nm can be generally attributed to chlorophyll-*b*, whereas the absorption between 660 and 680 nm arises predominantly from chlorophyll-*a* and therefore both chlorophyll species contribute to absorption around 660 nm. Krasnovksy *et al*. (1953) studied of chlorophyll-a in living plants and aqueous green extracts has revealed the presence of 2 forms of those pigments. They form with absorption peaks at about 673 and 683 nm which occur in various proportions. Meanwhile, Jeanette and French (1961) shown that when *Euglena gracillis* is cultured with light of low intensity (a. 250 ft-c), an absorption band at 695 nm was formed about 20% of the total chlorophyll absorption in the red region.

The reactions of photosynthesis can be divided into two main parts: light reactions and dark reactions (not requiring a light but require carbon dioxide), Lakitan (2001). Light reaction is a process to produce ATP (adenosine triphosphate), the unit of energy exchange in the cells and reduced the NADPH (nicotinamide adenine dinucleotide phosphate). This reaction requires water molecules. While in the dark reaction (Calvin cycle) occur reactions that form the basic ingredients of sugar from CO_2 and energy (ATP and NADPH). The energy used in the Calvin cycle is obtained from the light reaction (Raven and Johnson, 2002).

In the leaf, the light absorbed by chlorophyll molecules and collected at the reaction centers. Plants have two types of pigments which active as reaction center or photosystem, that is photosystem II and photosystem I. Photosystem II consists of chlorophyll molecules that absorb light at wavelength of 680 nm, whereas photosystem I at 700 nm (Raven and Johnson, 2002). Both photosystems will work simultaneously in the photosynthesis.

Photosynthesis begins when light ionizes the chlorophyll molecules in photosystem II, making them release electrons that transferred along the electron transport chain. The energy of these electrons is used for photophosphorylation which produces ATP. Reaction of photosystem II causes deficiency of electrons that must be replaced immediately. In plants and algae, the electron deficiency is filled by electrons from the ionization of water that occurs simultaneously with the ionization of chlorophyll. The results of water ionization are electrons and oxygen. At the same time, light also ionizes photosystem I, releasing electrons which are transferred along the electron transport chain which ultimately reduce NADP into NADPH (http://www.cartage.org.lb/en/themes/sciences/botanicalsciences/photosynthesis/photosynthesis/photosynthesis.htm 2012).

3. Experiment

3.1. Seed and Plant Media Preparation

Tomato seeds obtained from suppliers or special store seeds. The type of tomato used is *Tomato San Marino*. Prior to seedling, tomato seeds were soaked in water for ± 8 hours. A mixture of soil, manure and compost which kept in 11 pieces of polybags was used as plant media.

3.2. Cultivation of Seedlings

Tomato seeds that have been soaked for ± 8 hours were planted on plant media. Each medium was planted with 12 seeds of tomato with distance between seeds was ± 3 cm and then, covered the top of each sample with plant media for small amounts. Out of 11 samples, 7 of which were kept outside the room and 3 of them were kept in the laboratory for light treatment: irradiated with 650 nm and 680 nm light using transmitted glass filters, and one sample was kept in the wild as control. On the third day, the tomato seeds were starting to germinate.

3.3. Sample Treatment

Treatment of samples involved soil types used, fertilization and watering were the same for all samples. Six samples that were kept outside the laboratory room were transferred into the laboratory after ± 1 month ages (32 days) and then irradiate with light of 450 nm, 470 nm, 550 nm, 650 nm and 680 nm respectively using transmitted glass filters. The source light used was Halogen lamp, Philips, 100 W. Selection of ± 1 month age was based on preliminary research results that there were 2 phases of growth i.e. the first phase (germination phase) from age 0 to 18^{th} days that have higher growth speed than the second phase (vegetatif phase) from age 19^{th} to 53^{rd} days. So this study tried to improve the second phase, which was set at the age of 32^{nd} day of treatment performed. Each day, irradiation time was 10 hours, starting from 07:00 to 17:00 local time.

3.4. Observation

There were two types of observation in the study, that was observation of the height of plant and the contents or concentration of chlorophyll-a of plant leaves measured by UV-Vis spectrophotometer. The height of plant was measured by milimetre scale started from the surface of soil to the top of / shoots of plants.

Plant height

The observations of plant height was done every morning. The results were average height of plants in each sample.

Concentration of chlorophyll-a

The measurements of the concentration of chlorophyll-a were performed twice. First, at the 42^{nd} day old plant or 10 days after the plant were irradiated and second, at the 53^{rd} day old plant or 11 days after the first chlorophyll measurement. The concentrations of chlorophyll-a were measured using UV-Vis spectrophotometer DMS 70. The absorbance measurements for each sample were performed 3 times equally. Then the concentration of chlorophyll-a calculated by Jeffery and Humphrey method (Rupiasih, 2007):

$$\text{CHL a (mg / L)} = 11.93\, E_{664} - 1.93\, E_{647} \qquad (2)$$

Where:

E_{647} = the absorbance at wavelength of 647 nm
E_{664} = the absorbance at wavelength of 664 nm

4. Results and Discussions

4.1. The Growth of Tomato

The measurements of plant height were performed starting on the 3^{rd} untill the 53^{rd} days and the results are plotted in Figure 1 and 2. Based on each graph, there were created linear equations using

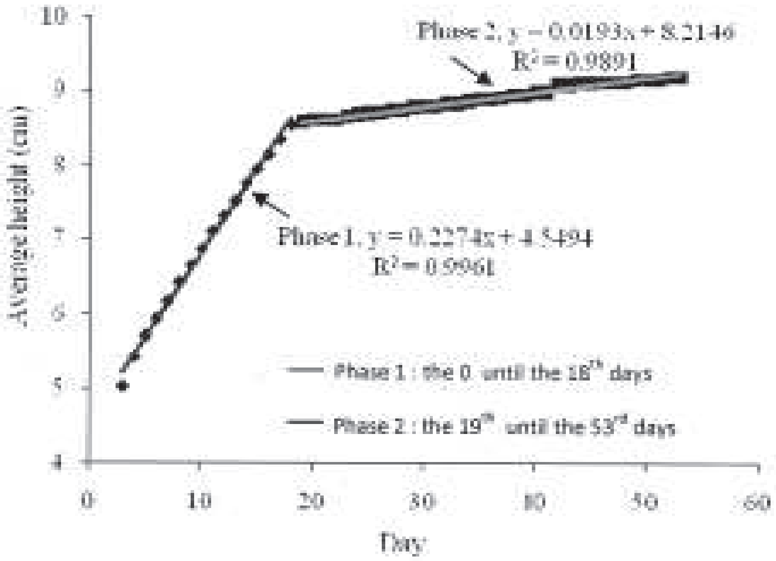

Figure 1. Graph of average height of tomato as function of time for tomato grown in the wild (or under direct sunlight).

linear regression method which were used to determine the growth rate of tomato plant, also presented on the both figures.

Figure 1 shows that, there are two phases of growth i.e. the first phase called germination/ seedling phase, starting on the 3rd until 18th days and the second phase called vegetatif phase, starting on the 19th until the 53rd days. The first phase has larger growth rate, 0.23 cm/day, compared with the second phase, 0.02 cm/day.

Based on those results, further investigation was focused on improving the growth rate in the second phase and was began on the 32nd day by exposing the plant to monochromatic light i.e. 450 nm and the results is presented in Figure 2.

Figure 2 shows that, the effect of radiation treatment that is monochromatic light: 450 nm starting on the 32nd day. These treatments were resulted the growth rate of tomato in 3 phases such as:

a. Phase 1 (the 3rd – 18th days), the growth rate was 0.21 cm/day.
b. Phase 2 (the 19th – 31st days), the growth rate was 0.02 cm/day.
c. Phase 3 (the 32nd – 53rd days, with radiation treatment, λ = 450 nm), the growth rate was 0.04 cm/day.

Furthermore, with the same method the data of growth rate of tomato plant with various wavelengths treatments presented in Table 1. In general, based on Figure 1, there are two phases of growth rate of tomato plant that are Phase 1, from 0 to 18th days and Phase 2, from the 19th day until the 53rd day. At Phase 1, the plant growth rapidly with average rate of 0.22 cm/day. When entering Phase 2 (vegetative phase), the phase of development of roots, stems and leaves, the average growth rate was slower than at Phase 1 i.e. 0.02 cm/day. To overcome the growth retardation in this phase, it was given a special treatment to the plant starting from the 32nd day by irradiating the plant with monochromatic light, namely: λ_1 = 450 nm, λ_2 = 470 nm, λ_3 = 550 nm, λ_4 = 650 nm, λ_5 = 680 nm and polychromatic light, and the data obtained were stated as Phase 3.

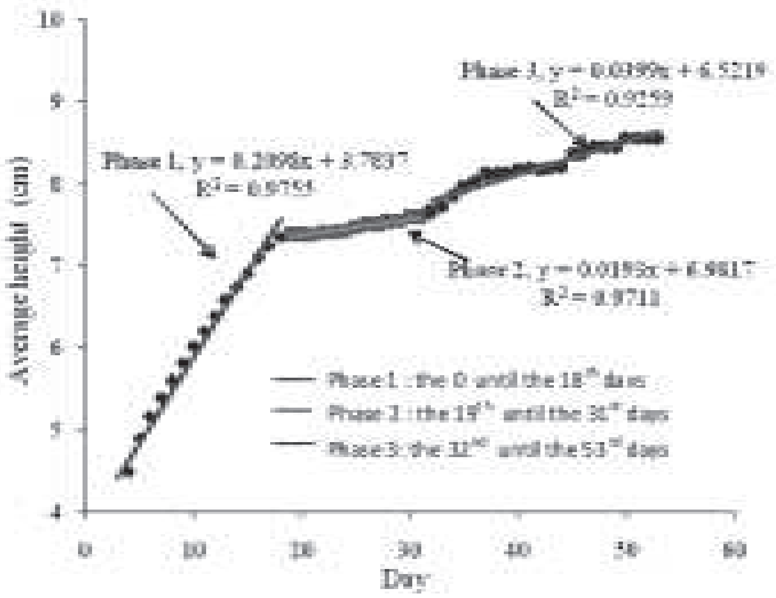

Figure 2. Graph of average height of tomato as function of time for tomato irradiated with monochromatic light (ë = 450 nm) started at the 32nd day.

Tabel 1. The average growth rate of tomato plant (cm/day) as function of various wavelengths.

The average growth rate of tomato (cm/day)			
Grown under the sunlight directly (control)		Grown under the various wavelengths treatments	
Phase 1 (the 3rd -18th days) (cm/day)	Phase 2 (the 19th-31st days) (cm/day)	λ (nm)	Phase 3 (the 32nd-53rd days) (cm/day)
0,21	0,02	450	0,04
		470	0,05
		550	0,04
		650	0,07
		680	0,06
		Polycro matic	0.04

Table 1 shows that, generally, the growth rate of treated samples were greater than the sample without treatment (grown in the wild). The greatest growth rate was occured at λ = 650 nm. This occurs because of heating effect of wavelength 650 nm gave an additional effective energy used for the process of growth and photosynthesis. Entering the 6th week onwards, the increasing of plant height also tends to slow down because at this age the plant enters the generative phase, where the formation and development of flower buds, fruits and seeds are going on.

Based on Table 1, the two greatest growth rates in Phase 2 were at λ = 650 nm and λ = 680 nm. For preliminary study was tried to improving the growth rate in Phase 1 began on 0 until 18th by exposing those wavelength, as well as polychromatic light and sun light directly as comparation. The results as shown in the Table 2.

Tabel 2. The average growth rate of tomato plant (cm/day) as function of various wavelengths in the first phase (germination phase)

The average growth rate of tomato in Phase 1 (cm/day)			
Grown under the sunlight directly (control), (the 0 -18th days) (cm/day)	λ (nm)	(0 – 8th days) (cm/day	(9th – 18th days) (cm/day)
0,21	650	0.01	die
	680	1.11	die
	Polychromatic	0.75	0.01

Based on Table 2, on germination phase, irradiation with wavelength of 680 nm has the greatest growth rate compared to other wavelengths, even greater than the germination under direct sunlight (or in the wild), especially on the 0 day until the 8th day, the average growth rate obtained was approximately 1.11 cm/day. However, after age 8th the plant died, this occurs because of heating effect of wavelength of 680 nm and also 650 nm gave an additional effectiveless energy used for the process of growth and photosynthesis or it required another wavelength.

4.2. Concentrations of Chlorophyll-a

Data of chlorophyll-a concentrations obtained by measuring of absorbance at wavelength of 647 nm and 664 nm (French, C.S., and Huang, H.S. 1957). The measurements were done 3 times at three stages, namely.

1. The first stage, before the samples were exposed to light.
2. The second stage, conducted after 10 days of sample exposed to light (on 42 days age of plant).
3. The third stage, conducted after 21 days of sample exposed to light (on 53 days age of plant).

Figure 3 shows that the concentration of chlorophyll-a was decreased in the third stage compared with the second stage as well as the first stage (6.669 mg/L). This was due to the occurrence of chlorosis (yellowing leaf events) along with increasing age of the plant. The graph also shows that the highest chlorophyll-a concentration was at wavelength of 650 nm, followed by 680 nm, 450 nm, 470 nm and the lowest was at 550 nm. When compared with control (in the wild) and polychromatic light, the sequence of chlorophyll-a concentrations from the highest to the lowest one are as follows: 650 nm, polychromatic light (6.79 mg/L), 680 nm, 450 nm, control (4.79 mg/L), 470 nm and 550 nm (for the second stage) and 650 nm, 680 nm,

The chlorophyll-a data obtained are plotted in Figure 3.

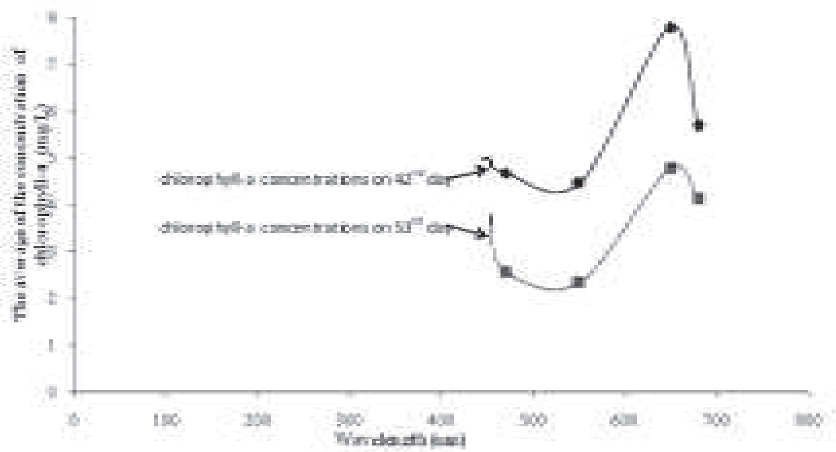

Figure 3. The average concentrations of chlorophyll-a as function of radiation wavelengths.

polychromatic light, 450 nm, control, 470 nm and 550 nm (for the third stage). The concentration of chlorophyll associated with the rate of photosynthesis that occurs in plants. In the theory stated that the maximum of chlorophyll-a concentration obtained at red wavelengths (650-700 nm) and blue wavelengths (400-500 nm). Those chlorophyll data obtained are agreed with the spectrum of photosynthesis action (Jone M, 2003), but the blue light effectiveless than red light. This is because although the optimal blue light is absorbed, but less energy generate heat effect for being used for photosynthesis.

5. Conclusions

Based on the results and discussions above, it is concluded that:

1. In general there are two phases of the growth rate of tomato plant is Phase 1 (germination phase) from 0 to 18th days and Phase 2 (vegetatif phase) from 19th to 53rd days in which, the growth rate at Phase 1 is greater than at Phase 2. To overcome the retardation of the growth rate Phase 2, there were carried out irradiation treatments on the plant with 450 nm, 470 nm, 550 nm, 650 nm, 680 nm and polychromatic light, started on the 32nd day.
2. Treatment with 650 nm light is the most effective radiation is used to accelerate growth in Phase 2 with an average growth rate of 0.07 cm/day, but less effective when used for germination.
3. For germination seeds directly illuminated by 680 nm light are most effectively used to accelerate the germination rate i.e. 1.11 cm/day.
4. Maximum level of cholophyll-a of tomato plant occurred at sample which irradiated by 650 nm light compared to other irradiated samples, where the concentration of chlorophyll-a is 7.784 mg/L for second stage (42nd day old plant) and 4.789 mg/L for the third stage (53rd day old plant).

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