Ikram et al., 2015

Volume 1 Issue 1, pp. 24-34

Year of Publication: 2015

DOI- https://dx.doi.org/10.20319/mijst.2016.s11.2434

This paper can be cited as: Ikram, M. M., Esyanti, R. R., & Faizal, A. (2015). The Effect of Photoperiodism with Led Light on Productivity of Female Flower in Cucumber (Cucumis Sativus L.). MATTER: International Journal of Science and Technology, 1(1), 24-34.

THE EFFECT OF PHOTOPERIODISM WITH LED LIGHT ON PRODUCTIVITY OF FEMALE FLOWER IN CUCUMBER (CUCUMIS SATIVUS L.)

Muhammad Maulana Malikul Ikram
School of Life Sciences and Technology, Institut Teknologi Bandung, Bandung, Indonesia
malikul.ikram@gmail.com

Rizkita Rachmi Esyanti
School of Life Sciences and Technology, Institut Teknologi Bandung, Bandung, Indonesia
rizkita@sith.itb.ac.id

Ahmad Faizal
School of Life Sciences and Technology, Institut Teknologi Bandung, Bandung, Indonesia
afaizal@sith.itb.ac.id

Abstract

Cucumber productivity can be optimize by regulating their photoperiod. Photoperiod will affect the production of female flower, the basis for the production of cucumber fruit. In this research, two cucumber lines (Mercy and KE 27187) was treated with 8, 12, and 16 hours of light by using red light (λ_{red} = 630 nm), blue light (λ_{blue} = 460 nm), and yellow light (λ_{yellow} = 510 nm) LEDs. Treatment from 12 h of light increased sugar accumulation (7482, 69 ppm) but not too different compared to 8 hours and 16 hours treatment. It also produced ethylene 27, 69% (v/v). Meanwhile, 16 hours treatment in KE 27187 line produced highest sugar accumulation (9178,59 ppm) and *ethylene production (21,92% (v/v)). High sugar accumulation and ethylene production could increase the production of female flower. In addition, 16 hours treatment resulted in the highest growth rate (2-4 times higher) and biomass dry weight (2-6 times higher) than other treatments. These results valid for both lines, Mercy and KE 27187. Using this LED Technology, we predicted that Mercy is a short-day plant and KE 27187 is a long-day plant.*

Keywords

Cucumis Sativus, Ethylene, Female Flowers, Led, Photoperiodism

1. Introduction

Cucumber (*Cucumis sativus* L.) is one of the biggest horticulture plants in Indonesia, with total sales reached 491.636 in 2013 with the land covering 49.296 Ha (Anonym 1, 2014). Cucumbers are commonly used as foods, cosmetics, and traditional medicines. Furthermore, their fruits produce cucurbitacin which is very potential as an anticancer agent. (Chen et al., 2005; Lee et al., 2010; Scout & Myers, 2010).

It is however, a number of pest infections has significantly reduced the production of cucumber in field. Generally, local farmers use insecticides to eradicate different kind of infections. Additional problem encounter in cucumber cultivation was unoptimal sexual determination, indicated by production of more male flowers. Alternatively, indoor cultivation offers controlled environmental conditions for cucumber growth and development, minimize pests and diseases which could reduce the use of pesticides, also allows production independent of place and weather (Anonym 2, 2012). Moreover, indoor cultivation need a replacement of sunlight, and until today, the leading edge of irradiation technology is LEDs (Light Emitting Diode) due to their high efficiency, monochromatic spectrum, and mercury-free unlike conventional light (Zukauskas et al., 2002, Massa et al., 2008).

Danielson reported that daylength has a critical influence on flower production in cucumber (Danielson, 1944), Plants exposed to 8 h light resulted in highest of flower production compared to those plants treated with 12 and 16 h light. Short day condition also promoted femaleness in cucumber plants (Yamasaki, et al., 2003). This could be explained by the fact that short day irradiation could increase ethylene production which induce more female flowers (Yamasaki et al., 2003). In addition to light, high content of sucrose was also correlated to higher production of ethylene (Miao et al., 2010). Based on these previous results, we performed a study to evaluate the effect of photoperiod using LEDs on sexual determination in two lines of cucumbers, i.e. Mercy and

KE 27187.

2. Materials and Methods

Plant Materials

Two lines of cucumbers (Mercy and KE 27187) were germinated on wetted straw paper for 3 days. Subsequently, seedlings were transferred to charcoal husks and were maintained in growth chamber, with controlled temperature 24-26 ^{o}C and air moisture content 5-6%.

LED Treatment

LEDs used in this experiment comprise of red light (λ_{red} = 630 nm), blue light (λ_{blue} = 460 nm), and yellow light (λ_{yellow} = 510 nm) with Photosynthetic Active Radiation (PAR) of 10-90

µmol.m^{-2}.s^{-1} and light intensity 110 – 2000 lux. Power input for each LED was 1 watt. As control, we used two High Pressure Sodium (HPS) lamps combined with 12 Tube Light (TL) lamps which resulted to PAR 50 – 210 µmol.m^{-2}.s^{-1} and intensity 1960 – 6000 lux. Power input for both HPS and TL was 36 watt and 400 watt, respectively.

Treatments with LEDs were divided into 8, 12, and 16 h irradiation. Measurement of plants height and numbers of flowers was conducted two times a week. Plants were watered using half liter of tap water each day until 3 weeks, and then watered with a liter/day until harvest. Twenty g of NPK (16:16:16) mixture was given as a basal fertilizer for each individual plant. For the first two weeks, each plant was given additional 2 g of Growmore^{TM} N, followed by 1 g of Growmore^{TM} PK 1.

Measurement of Sugar Content

At the last day of cultivation, fully developed apical leaves from both lines were harvested according to Yamasaki, et al. (Yamasaki et al., 2003). Sugar content was measured by using ferricyanide reducing sugar assay (Liu & Jiang, 2001).

Quantification of Ethylene Content

Quantification and sample collection of ethylene were referred to Yamasaki, et al. (Yamasaki et al., 2003). Apical shoots was excised and directly stored in an air-tight vial to entrap ethylene. Ethylene content was further quantified using a Gas Chromatography-Mass

Spectrophotometer (GCMS).

Statistical Analysis

Data were analyzed using one way ANOVA and the comparison of cucumber dry weight was contrasted using Duncan Test at the level of p value less than 0, 05 using SPSS Software version 22nd.

Mass Balance Modeling

Modeling for mass balance was based on the following equation (Saterbak, et al., 2007).

$$aC_{12}H_{22}O_{11} + bNH_4NO_3 + cO_2 \rightarrow dCH_{1.27}O_{0.43}N_{0.45} + eH_2O + fCO_2 \quad (1)$$

Coefficient reaction value for each component (a,b,c,d,e,f) acquired from element balance of carbon (C), hydrogen (H), oxygen (O), and nitrogen (N). Hypothetical dry weight was obtained with assumption that all fertilizer converted into NH_4NO_3 and servedas limiting reactant. Actual dry weight from experiments was used to compare hypothetical and actual data to validate our mass balance model.

Analysis of Plant Growth Rate

Growth rate was measured according to the following formula (Shuler & Kargi, 2001):

$$\mu = (\ln(X_2) - \ln(X_1))/ (t_2 - t_1) \quad (2)$$

M is growth rate (cm/week), X_2 is plant height at time 2 (cm), X_1 is plant height at time 1 (cm), and it is time (week). Plant height was obtained from actual data.

Growth Kinetics Modeling

Modeling for growth kinetics was based on logistics equation (Paine, et al., 2012).

$$dX/dt=\mu X(1-X/X_{max}) \quad (3)$$

Growth rate used in this equation was obtained from Equation 2, initial height and maximum height was obtained from actual data. Hypothetical growth rate acquired from this equation was compared to the actual growth rate to evaluate our model.

3. Results and Discussion

3.1 Sugar Content

Sugar content from both lines is depicted in Table 3.1. Our result showed that 16 h irradiation enhances plant sugar content for both lines compared to 8 and 12 h treatments. Xu et al. also reported the same result that the longer light exposure treated to the plant, the carbohydrates will accumulated higher as well (Xu et al., 2004). This result could be explained that longer irradiation produce higher energy from photosynthesis to be used in calvin cycle, therefore the sugar production in calvin cycle was also elevated (Taiz & Zeiger, 2002).

3.2 Ethylene Content

Ethylene content in plants could only be detected on 12 h light treated in Mercy line, and 16 h in KE 27187 line (Table 3.2). This result was positively correlated to the respective sugar content in both lines. Similarly, Miao, et al., (Miao et al., 2010) also reported that sugar was highly accumulated in accordance to high level of ethylene.

Table 3.1: *Total Sugar Content in Cucumber Apical Leaf*

Treatment		**Sugar content (ppm)**
8 h of light	Mercy	7125,06
	KE 27187	6202,12
12 h of light	Mercy	7482,69
	KE 27187	7113,52
16 h of light	Mercy	7748,04
	KE 27187	9178,59

Table 3.2: *Ethylene Production in Cucumber Apical Shoots*

Treatment	Line	Ethylene (% Area (v/v))
8 h of light	Mercy	-
	KE 27187	-
12 h of light	Mercy	27,96%
	KE 27187	-
16 h of light	Mercy	-
	KE 27187	21,92%

3.3 Photoperiod Affects Determination Cucumber Flowers

Maximum number of flowers for each photoperiod is shown in Figure 3.1. Twelve hours treatment resulted in the highest number of female flowers for Mercy (2, 2 flower/plant). Interestingly, prolonged light treatment for 16 hours significantly increase the number of female flowers in KE 27187 line (12, 2 flower/plant). This result indicated that high level of ethylene had a positive correlation with female flower development and this outcome in line with Yamasaki, et al. research (Yamasaki et al., 2003). In addition, sugar content also played a role as a signal and energy supply in development of flowers (Taiz & Zeiger, 2002).

Based on sugar content, ethylene production, and flowers, we could draw a conclusion that Mercy line is a neutral day plant and KE 27187 is a long day plant. Though, this outcome was different from Yamasaki that stated cucumber was a short day plant (Yamasaki, et al., 2003). Hence, analysis of other factors that affect the production of female flowers in addition to photoperiod were needed. One factor that might played a role in determination of cucumber flower is light. Energy produced by LEDs used in this experiment did not sufficient for plant to maximize the female flowers production (Moore, 2008), while PAR required for cucumber was 115,74 - 350 $\mu mol.m^{-2}.s^{-1}$(Torres & Lopez, 2010) and PAR excited from the LED is only 10 – 90

$\mu mol.m^{-2}.s^{-1}$.

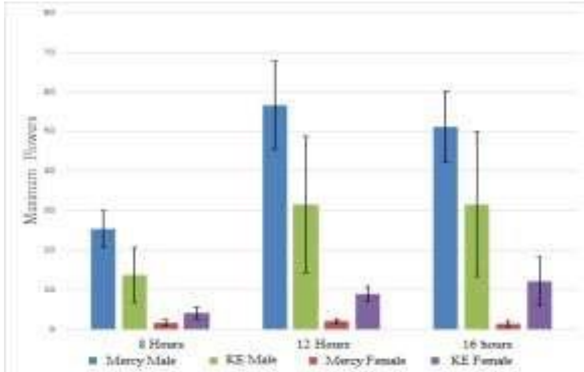

Figure 3.1: *Maximum Flowers observed in Mercy and KE 27187 lines*

Table 3.3: *Final Dry Weight from Mercy and KE 27187 line*

Treatment	**Mercy (g)**	**KE 27187 (g)**
8 h of light	3,00 $\pm$ 0,27^{c}	2,22 $\pm$ 0,04^{c}
12 h of light	7,68 $\pm$ 1,08^{b}	7,27 $\pm$ 1,34^{b}
16 h of light	15,64 $\pm$ 0,11^{a}	12,42 $\pm$ 1,51^{a}

Dry weight value calculated from average dry weight + Standard Error of Mean (SEM) Different letter showed difference in significance based on Duncan Test ($p < 0, 005$)

Plants Dry Weight

Final dry weight from treatment of 8, 12, and 16 hours of photoperiod was shown in Table 3.3.Completion of mass balance equation from Equation 1 was given in Table 3.4. with the complete equation given in Equation 4. Fertilizer addition along the cultivation was 44 g, thus the initial mole of NH_4NO_3 was 0,55. All fertilizer reacts and act as a limiting reactant that resulting final biomass mole 2, 3919 with final biomass 63, 25g (MW Biomass: 63, 25).

From Table 3.3, actual dry weight that closest to the hypothetical was 16 hours of light because of longest photosynthetic (Xu, et al., 2004). Thus, the mass balance modeling did not predicted dry weight of plants in this cultivation because the model did not reckon with numerous factors, e.g. light intensity, PAR, oxygen, etc.

Growth Rate and Growth Modeling

Modeling was conducted to calculate hypothetical growth rate that will be compared to actual growth rate. Table 3.5 and 3.6 showed comparison of hypothetical and actual growth rate for Mercy and KE 27187 line, respectively.

Modeling was performed based on logistic equation (Equation 3) by fitting with actual data. This models showed that the closest actual growth rate with the hypothetical was 16 hours of light because the photosyntate production were highest, therefore provide better growth than other treatment (Xu et al., 2004). This models did not perform well to modeling of the growth rate of plants because it did not accounted factors that affect the growth rate, e.g. light intensity and PAR that had a role as main variable in this research.

$$0,39\ C_{12}H_{22}O_{11} + 0,23\ NH_4NO_3 + 3,43\ O_2 \rightarrow CH_{1,27}O_{0,43}N_{0,45} + 4,07H_2O + 3,64CO_2 \quad (4)$$

Table 3.4: *Mass Balance Equation*

	$C_{12}H_{22}O_{11}$	NH_4NO_3	O_2	$CH_{1,27}O_{0,43}N_{0,45}$	H_2O	CO_2
Initial (mole)	-	0,55	-		-	-
Reaction (mole)	0,93	0,55	8,20	2,39	9,73	8,70
Final (mole)	-	0	-	2,39	9,73	8,70

Table 3.5: *Comparison of Hypothetical and Actual Growth Rate from Mercy Line*

Mercy line	**8 h of light**	**12 h of light**	**16 h of light**
Hypothetical(cm/week)	0,068	0,095	0,092
Actual(cm/week)	0,0126	0,028	0,0413

Table 3.6: *Comparison of Hypothetical and Actual Growth Rate from KE 27187 Line*

KE 27187 line	**8 h of light**	**12 h of light**	**16 h of light**
Hypothetical(cm/week)	0,069	0,109	0,094
Actual(cm/week)	0,0105	0,0242	0,0308

Table 3.7: *Consumption Energy Analysis from Each Female Flowers Produce*

Treatment	**Energy Consumption (kWh/flower.batch)**
Mercy 12 h of light	24,74
Mercy Control	18,48.
KE 27187 16 h of light	5,95
KE 27187 Control	3,67

Energy Consumption

Economy analysis was conducted to calculate the energy expenditure to produce each female flower; thereby the cost of energy could be calculated and compared for each treatment. Comparison of energy consumption showed us which treatment that gave more profit in production of cucumber. The best photoperiod treatment that produces highest female flowers in each line was compared to control treatment from TL+HPS light.

Table 3.7 revealed that LED treatment still consumed higher energy than control treatment; therefore the cost for electricity might be higher with LED treatment than control. These result were affected by unoptimized LED that gave insufficient PAR to cultivated cucumber. As stated before, PAR required for cucumber was 115,74 - 350 $\mu mol.m^{-2}.s^{-1}$(Torres & Lopez, 2010), while PAR from TL+HPS and LEDs was 50 - 210 $\mu mol.m^{-2}.s^{-1}$and 10 – 90$\mu mol.m^{-2}.s^{-1}$, respectively. For this reason, LEDs used in this experiment did not provide adequate PAR for cucumber growth and development compare to TL+HPS.

4. Conclusion and Suggestion

Best photoperiod for growth parameter (growth kinetics and actual dry weight) in both lines was 16 hours of light. This result was in line with other research that longer photoperiod would give plant more time to photosynthesis, led to higher sugar accumulation which was also observed in this experiment. Best production of female flower, ethylene, and sugar content that led to production of female flowers in Mercy lines was obtain by 12 hours treatment of light and for KE 27187 was 16 hours of light. Twelve hours of light in Mercy line gave an optimal photoperiod to promote development of female flower in cucumber by inducing ethylene production and through sugar signalling. This result indicated that Mercy might be a neutral day plant. Meanwhile, 16 hours of light in KE 27187 line gave an optimal photoperiod to induce female flower development which indicated that KE 27187 might be a long day plant, or alternatively, 16 hours of light gave KE 27187 the highest photosyntate (sugar content) that accommodated the production of female flowers via ethylene and sugar signalling. Therefore, not only photoperiod that affects the production of female flowers, PAR and light intensity also played a role to generate energy that accommodated production of female flowers. Energy analysis showed that recent LED used in research was not yet profitable for indoor agriculture.

Further research was expected to optimize the LED equipment, so that PAR and light intensity needed by plants will be fulfilled and impacted to the increase of female flowers production, thereby compensated the cost of energy and made the indoor agriculture more profitable.

5. Acknowledgment

The authors thank PT. East West Seed Indonesia for the contribution in this research by facilitating all the plants, cultivation, and equipment.

References

Anonym 1, (2014), Ministry of Agriculture Indonesia Republic, Produksihortikulturasaatini.http://aplikasi.pertanian.go.id/bdsp/index.asp

Anonym 2, (2012), PlantLab, Plant Paradise : emancipation of the plant. The art of giving plants what they want, http://www.plantlab.nl/lets-get-real-agriculture/

Chen J.C., Chiu M.H., Nie R.L., Cordell G.A., and Qiu S.X.., (2005), Cucurbitacins and cucurbitane glycosides: structures and biological activities, Natural product reports, 22, p. 386-399.

Danielson, L.L., (1944), Effect of Daylength on Growth and Reproduction of the Cucumber, Plant Physiology, 19(4), hlm. 638-648.

Lee D.H., Iwanski G.B., and Thoennissen N.H., (2010), Cucurbitacin: ancient compound shedding new light on cancer treatment, Scientific World Journal, 10(3), p. 413-418.

Liu, Jing-fu, and Gui-bin Jiang, (2001), Spectrophotometric flow injection determination of total reducing sugars in tobacco based on oxidation by ferricyanide and formation of Prussian blue, Analytical letters 34.11 p. 1923-1934.

Massa G. D., Kim H. H., and Wheeler R. M., (2008) Plant productivity in response to LED lighting. Horticultural Science, vol. 43, No. 7, p. 1951-1956.

Minmin Miao, Xiaguang Yang, Xiaoshuang Han, and Kuishan Wang., (2010), Sugar signalling is involved in the sex expression response of monoecious cucumber to low temperature, Journal of Experimental Botany, p. 1-8, 2010.

Saterbak, Ann, Mc Intire, Larry V., (2007), San, and Ka-Yiu, Bioengineering Fundamentals, Pearson Prentice Hall.

Shuler, Michael L., and Kargi, Fikret, (2001), Bioprocess Engineering : Basic Concepts 2nd edition, Prentice Hall International Edition.

Torres, A.P., and Lopez, R.G., (2010), Measuring Daily Light Integral in a Greenhouse, Commercial Greenhouse Production, HO-238-W, Purdue Extension, Purdue University, 2010.

Xu Q, Huang B, and Wang Z, (2004), Effects of Extended Daylength on Shoot Growth and Carbohydrate Metabolism for Creeping Bentgrass Exposed to Heat Stress, Soc.Hort.Sci 129: 193-197.

Yamasaki, S., Fujii N., and Takahashi H., (2003), Photoperiodic regulation of CS-ACS2, CS-ACS4, and CS-ERS gene expression contributes to the femaleness of cucumber flowers through diurnal ethylene production under short-day conditions, Plant Cell and Environment, 26, p 537-546,.

Zukauskas A., Shur M., and Gaska R, (2002), Introduction to Solid-State Lighting. New York, p.220.