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Effects of artificial light sources on growth and phytochemicals content in green oak lettuce

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ABSTRACT

The artificial light source is one of the most important factors in a controlled environment for vegetable production. It could provide new opportunities to improve growth and increase phytochemicals content in vegetables. Therefore, this study focused on the effects of artificial light sources on growth and phytochemicals in green oak lettuce (*Lactuca sativa*). The plants were grown under growth chamber with three artificial light sources, namely bar-LED (the 1:1:1 ratio of blue 460 nm : red 630 nm : red 660 nm), bulb-LED (the 2:1:1 ratio of blue 460 nm : red 630 nm : red 660 nm), and fluorescent lamp (FL) (the wavelength range 380-700 nm) for 4 weeks. The quality of bar-LED light was better than either bulb-LED or FL, when assessed by the parameters of photosynthetically active radiation (PAR), photosynthetic photon flux density (PPFD, 400-700 nm), PPFD-B (blue, 400-500 nm), PPFD-R (red, 600-700 nm), the yield photon flux density (YPFD), and the color of red. However, shoot and root (fresh and dry mass), leaf area, leaf number, and shoot/root ratio did not significantly differ between plants grown under bar-LED and bulb-LED, but they were significantly higher than plants grown under FL. Bulb-LED and bar-LED induced larger dry mass of the plants than FL. The dry mass per mole of artificial lighting was highest in plants grown under bar-LED. On the other hand, the fresh mass per mole of artificial lighting was highest in plants grown under bulb-LED. As regards power consumption, bar-LED provided the lowest consumption with 44.4% energy saving over the FL. Total phenolic content, 2,2'-azino-bis (3-ethylbenzthiazoline-6-sulphonic acid) (ABTS) and 2,2-diphenylpicrylhydrazyl (DPPH) activities were highest in plants grown under bar-LED. FL lighting gave the least contents of chlorophyll *a* and chlorophyll *a* + *b*. However, chlorophyll *b* and carotenoid contents did not significantly differ among the treatments. Thus, the results suggested that bar-LED has the potential to improve energy saving, and both growth and phytochemicals content of green oak lettuce grown in a controlled environment of vegetable production.

Keywords: *Lactuca sativa*, controlled environment, light spectrum, phytonutrients.

RESUMO

Efeitos de fontes de luz artificiais no crescimento e no conteúdo de fitoquímicos de alface green oak

A fonte de luz artificial é um dos fatores mais importantes em um ambiente controlado para a produção de vegetais. Ela pode melhorar o crescimento e aumentar o conteúdo de fitoquímicos nos vegetais. Portanto, este estudo enfocou os efeitos de fontes de luz artificiais no crescimento e fitoquímicos em alface green oak (*Lactuca sativa*). As plantas foram cultivadas em câmara de crescimento com três fontes de luz artificial, a saber: bar-LED (proporção 1:1:1 de azul 460 nm: vermelho 630 nm: vermelho 660 nm), bulb-LED (proporção 2:1:1 de azul 460 nm: vermelho 630 nm: vermelho 660 nm) e lâmpada fluorescente (FL) (faixa de comprimento de onda 380-700 nm) por 4 semanas. A qualidade da luz de bar-LED foi melhor que a de bulb-LED ou FL, quando avaliada pelos parâmetros de radiação fotossinteticamente ativa (PAR), densidade de fluxo de fótons fotossintéticos (PPFD, 400-700 nm), PPFD-B (azul, 400-500 nm), PPFD-R (vermelho, 600-700 nm), densidade do fluxo de fótons (YPFD) e cor vermelha. No entanto, a parte aérea e a raiz (massa fresca e seca), a área foliar, o número de folhas e a relação parte aérea/raiz não diferiram significativamente entre as plantas cultivadas sob bar-LED e bulb-LED, mas foram significativamente maiores que as plantas cultivadas sob FL. O bulb-LED e o bar-LED induziram maior massa seca das plantas que o FL. A massa seca por mole de iluminação artificial foi maior nas plantas cultivadas sob bar-LED. Por outro lado, a massa fresca por mole de iluminação artificial foi maior nas plantas cultivadas sob bulb-LED. Em relação ao consumo de energia, o bar-LED forneceu o menor consumo, com 44,4% de economia de energia em relação ao FL. O conteúdo fenólico total, as atividades 2,2'-azino-bis (ácido 3-etilbenztiazolina-6-sulfônico) (ABTS) e 2,2-difenilpicliril-hidrazil (DPPH) foram maiores nas plantas cultivadas sob bar-LED. A iluminação FL resultou em menor conteúdo de clorofila *a* e clorofila *a* + *b*. No entanto, os teores de clorofila *b* e carotenóide não diferiram significativamente entre os tratamentos. Assim, os resultados sugeriram que o bar-LED tem potencial para maior economia de energia e o conteúdo de fitoquímicos e crescimento de alface green oak cultivada em ambiente controlado de produção vegetal.

Palavras-chave: *Lactuca sativa*, ambiente controlado, espectro de luz, fitonutrientes.

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Vegetables are essential and beneficial to human health because they are rich in vitamins, minerals, fiber, and phytochemicals, especially antioxidants. Antioxidants play an essential role in protecting and preventing cardiovascular disease, high blood pressure, inflammation, and aging (Slavin & Lloyd, 2012). Lettuce is an important vegetable that is popular among consumers around the world. It benefits human health by its high contents of fiber, iron, folate, ascorbic acid, and other bioactive compounds and it is low in calories, fat and sodium (Kim *et al*., 2016). In addition, lettuce consumption can prevent degenerative diseases, for example, cardiovascular disease (Nicolle *et al*., 2004). Currently, the demand for vegetables tends to increase because people much concern in a healthy lifestyle by consuming good quality food. Moreover, the world's population will reach 9.3 billion by 2050 (Food and Agricultural Organization, 2009). However, global vegetable production is still faced with many problems, such as climate change, shortage of water and soil problems. In addition, agriculturists migrate into the big cities looking for new jobs, and then the population of agriculturists tends to decrease. Therefore, vegetable production is a major concern for food security in the future. Controlled environment cultures can produce higher quantity and quality of vegetables per unit and reduce the losses or costs incurred by weeds, fungi, bacteria, insects, water and nutrition management, labor, and land area used. However, light is an important factor in the controlled environment.

In general, light is the main source of energy for photosynthesis and it also regulates growth and development. For plant photosynthesis, red light (600 to 700 nm) is more efficient than blue light (400 to 500 nm) and green light (500 to 600 nm) by 25-35% and 5-30%, respectively (McCree, 1972). The quality of lighting also affects plant growth and development (Ahmad *et al*., 1995). However, photosynthesis efficiency also varies by plant species (Schuerger *et al*., 1997). Mostly, plant production in the controlled environment system mainly uses artificial light source. Consequently, artificial light source has become an issue of interest in the vegetable production (Massa *et al*., 2008).

Currently, common artificial light sources include Incandescent Lamp (IL), High-Pressure Sodium Lamp (HPSL), Metal Halide Lamp (MHL), Fluorescent Lamp (FL) and Light-Emitting Diode (LED) (Massa *et al*., 2008). However, the different types of artificial light sources have various light qualities for plant growth. For example, IL is primarily used to extend the lighting time during seasons with short daylight period. Though, IL converts only 15% of the electric power used to light for plant photosynthesis, while the remaining 85% is converted to heat that is not useful and can be harmful to the plants (Massa *et al*., 2008). HPSL is widely used in vegetable production, but it can convert only 30% of the electric power intake to light (Bian *et al*., 2015). Recently, FL has been commercially applied in cultivating vegetables. It used less electric power and provided better plant growth than IL or HPSL (Shoji *et al*., 2013). In Japan, about 60% of plant factory farms use FL as the light source (Shoji *et al*., 2013). However, LED lamps are a novel light source for plant cultivation. Many studies revealed that different types of LED could affect plant growth in terms of quantity and quality (Ruangrak & Khummueng, 2019). However, there is no compared information how the different spectrum ratio of LED promotes the growth and phytochemicals content on green oak lettuce under controlled environment. Therefore, this research aimed to study the effects of the artificial light sources of bar-LED, bulb-LED and FL on plant growth and phytochemicals content in green oak lettuce.

MATERIAL AND METHODS

Plant material and growth conditions

Seeds of green oak lettuce cultivar "Iceland" (*Lactuca sativa*) were germinated in polyfoam cubes (2.5×2.5×2.5 cm) and placed in the nursery greenhouse for 15 days. After that, the seedlings were transplanted into a growth chamber [240 width x 170 height x 40 depth (cm)] consisted of three shelves, each of which was divided into three chambers. The chambers [80 width x 30 height x 40 depth (cm)] were lightened from above with artificial light sources as following each treatment and placed the seedlings with 20x20 cm distance between plants. Aeration pump and sandstones were applied to aerate the nutrient solution (Sirinupong, 2017). The stocks of the nutrient solution included A solution [50 g L^{-1} magnesium sulfate, 78 g L^{-1} potassium nitrate, 13 g L^{-1} mono ammonium phosphate, 10 g L^{-1} monopotassium phosphate, 0.8 g L^{-1} manganese EDTA, 1 g L^{-1} microelements (1.7% boron, 1.8% manganese, 7.0% magnesium, 1.9% copper, 0.01% molybdenum and 1.8% iron)] and B solution (10 g L^{-1} calcium nitrate and 1 g L^{-1} iron chelate). The nutrient solution was maintained at pH 6 with 2.0 mS cm^{-1} electrical conductivity and had a 12 h photoperiod (12 h light/12 h dark). The air temperature and relative humidity were maintained at 28-30°C and 75-85%, respectively, in all treatments. The plants were transplanted during the August 2018 and harvested at 28 days after transplanting. This experiment was conducted at the Laboratory of Urban Agriculture Technology, Division of Agricultural Technology, Department of Technology and Industry, Prince of Songkla University, Pattani Campus, Pattani Province, Thailand.

Light treatments and measurements

Three commercial light sources were used: 1= FL (TOSHIBA (18 W) gave the wavelength range 380-700 nm; 2= Bulb-LED [Ting-Mao Technology, Taipei, Taiwan (4W)] gave red light (630-660 nm) and blue (460 nm) in the 2:1:1 ratio of blue 460 nm : red 630 nm : red 660 nm; 3= Bar-LED [Ting-Mao Technology, Taipei, Taiwan (30 W)] gave red light (630-660 nm) and blue (460 nm) in the 1:1:1 ratio of blue 460 nm : red 630 nm : red 660 nm. Eleven light quality characteristics were determined by a plant light spectrum analyzer (OHSP-350P, Hangzhou Hopoo Optical Color Technology Co., Ltd), photosynthetically active radiation

(PAR), photosynthetic photon flux density (PPFD, 400-700 nm), PPFD-UV (ultraviolet, 280-380 nm), PPFD-B (blue, 400-500 nm), PPFD-G (green, 500-600 nm), PPFD-R (red, 600-700 nm), PPFD-FR (far-red, 700-800 nm), the yield photon flux density (YPFD), and the color ratio of red (R), blue (B), and green (G).

Measurements indicative of plant growth included leaf number (LN), leaf area (LA), total LA, shoot fresh mass (FM), root FM, total FM, shoot/root ratio (S/R) by FM, shoot dry mass (DM), root DM, total DM, S/R ratio by DM, and water content (WC). LA was determined per leaf and total; LA was measured per plant with an easy leaf area application in a smartphone (vivo Y51) as mentioned in Easlon & Bloom (2014). Electrical analysis balance (AB204-S Metler Toledo Switzerland) was applied for shoot FM, root FM, total FM, shoot DM, root DM and total DM. Hot air oven (Binder Scientific Promotion Co., Ltd) was used to dry plant samples at 65ºC for 48 h. Leaf thickness (LT) was estimated as $(SLA \times LDMC)^{-1}$, using specific leaf area (SLA) and leaf dry matter content (LDMC), calculated in turn as LA/DM and leaf DM/FM, respectively (Vile *et al*., 2005). Chlorophyll (chl) and carotenoid (car) contents were determined according to Lin *et al*. (2013).

Plant productivity by power consumption was calculated as FM and DM in grams vs. light in moles meter^{-2}. Normalized plant production values were assumed at similar plant biomass production from artificial light and calculated production rates were based on the percentage of artificial light sources (DM produced by artificial lighting = DM m^{-2}) (Martineau *et al*., 2012).

Phytochemicals content and total soluble sugar content (TSSC) were measured by the adapted method of Lin *et al*. (2013). The solution, ethanol (80% V/V) and 2% anthrone reagent (0.2 g anthrone was dissolved in 100 mL sulphuric acid) were kept in an ice bath. D-glucose was used as standard. The sample was prepared by adding 0.05 g dry shoot powder with 5 mL distilled water into a 10 mL test tube and mixed gently. The supernatant was collected after keeping the sample in a water bath at 85ºC for 30 min, and then this step was repeated. The volume was made up with distilled water to 10 mL. A 1.0 mL aliquot of the extract solution was pipetted into a test tube and cooled down on the ice. Then, 4 mL anthrone reagent was added and the mixture was heated for 10 min at 100ºC and cooled down immediately on ice. Finally, the solution was subjected to measurement of the TSSC by 620 nm wavelength. Ascorbic acid content measurement was modified from Jagota & Dani (1982). A 7 g leaf sample (fresh weight) was weighed and immediately added to 14 mL oxalic acid (0.5% w/v) to prevent oxidation and filtered through a filter paper (no. 1). A 1 mL sample of the extract was mixed with 4 mL of 10% trichloroacetic acid, then immediately placed on ice for 5 min. Centrifugation was performed at 8,000 rpm for 5 min. Then 3 mL of the supernatant was mixed with 0.2 mL of 0.2 M Folin-Ciocalteu reagent and incubated at room temperature for 60 min. Finally, a spectrophotometer (Biochrom Libra S12 UV-Vis Spectrophotometer) was used at 760 nm for measurement. Measurements of total phenolic content (TPC) and 2,2-diphenylpicrylhydrazyl (DPPH) free radical scavenging activity were done as previously reported by Sulaiman *et al*. (2011). The 2,2'-azino-bis (3-ethylbenzthiazoline-6-sulphonic acid) (ABTS) radical cation decolorization assay was done as described by Re *et al*. (1999), and nitrate content was measured as in Lastra (2003).

The experimental design was completely randomized with three replications. The statistical analysis was performed with the R software (R i386 3.4.1). Mean differences were subjected to Duncan's Multiple Range Test (DMRT) at a 95% level of significance.

RESULTS AND DISCUSSION

Light quality

The light quality parameters for the three artificial light sources are shown in Table 1. The results show that bar-LED had the highest light quality parameters of PAR, PPFD, PPFD-B, PPFD-R, YPFD, and color ratio of R with a significant difference to the others. However, bulb-LED and FL were not different in the light quality parameters of PAR, PPFD and YPFD. The values of PPFD-UV, PPFD-G, PPFD-FR, and the color ratio of G were the highest for FL. The color ratio of B was not distinct between bulb-LED and bar-LED. PAR, PPFD, PPFD-B, PPFD-R, YPFD, and the color ratio of R and B are important light quality characteristics, which are related to plant photosynthesis, growth and development (Li & Kubota, 2009; Park & Runkle, 2018). According to the results, these parameters were comparatively high in bar-LED light followed by bulb-LED and FL. In contrast, characteristics that are not relevant to plant photosynthesis, growth and development, namely PPFD-UV, PPFD-G, PPFD-FR, and the color ratio of G, were comparatively high for FL.

Plant growth

As presented in Table 2, the LA, total LA, LN, S/R ratio (DW) and WC were higher in plants grown under bulb-LED and bar-LED than in plants grown under FL. Similarly, the shoot, root and total FM and DM of plant grown under bulb-LED did not differ from bar-LED, whereas they distinguished from FL (Table 2). The SLA was significantly higher with bulb-LED than bar-LED and FL. On the other hand, S/R ratio (FW), LT and LDMC showed no difference among the treatments (Table 2).

Plant productivity and power consumption

FL and bulb-LED light sources had no difference in FM per mole of artificial lighting, while bar-LED was significantly highest (Table 3). However, the DM per mole of artificial lighting was not distinctly significant with plants grown under bar-LED and bulb-LED, but they were significantly larger than FL. DM produced by artificial lighting was higher in bar-LED and bulb-LED than FL. Moreover, bar-LED and bulb-LED were power saving compared with FL for 44.4% and 11.1%, respectively. However, a previous study has reported increased FW when using red LED to culture lettuce, while the DW was

Table 1. Light quality parameters; photosynthetically active radiation (PAR), photosynthetic photon flux density (PPFD), PPFD-UV (ultraviolet), PPFD-B (blue), PPFD-G (green), PPFD-R (red), PPFD-FR (far-red), the yield photon flux density (YPFD), and the color ratio of red (R), green (G), and blue (B) of the three artificial light sources [fluorescent lamp (FL), bar-light-emitting diode (bar-LED) and bulb-light-emitting diode (bulb-LED)]. Pattani, Prince of Songkla University, 2018.

Light quality parameter	FL	Bulb-LED	Bar-LED
PAR (mW cm^{-2})	0.87 ± 0.16b	0.99 ± 0.02b	2.42 ± 0.12a
PPFD (μmol m^{-2}s^{-1})	35.76 ± 6.78b	44.98 ± 1.28b	111.33 ± 5.89a
UV	1.12 ± 0.17a	0.02 ± 0.02b	0.10 ± 0.01b
B	12.00 ± 2.27c	19.22 ± 1.51b	43.35 ± 1.80a
G	16.41 ± 3.01a	0.83 ± 0.33b	1.40 ± 0.09b
R	7.36 ± 1.51c	24.93 ± 1.79b	66.57 ± 4.16a
FR	1.53 ± 0.19a	0.30 ± 0.10c	0.69 ± 0.04b
YPFD (μmol m^{-2}s^{-1})	30.69 ± 5.81b	37.69 ± 1.42b	96.08 ± 5.39a
Color ratio (%)			
R	11.92 ± 0.30c	52.77 ± 6.38b	65.77 ± 2.83a
G	83.85 ± 0.34a	14.60 ± 2.54b	10.03 ± 0.21c
B	4.25 ± 0.03b	32.63 ± 8.17a	24.19 ± 2.84a

Mean ± SD values followed by a different letter in the same row are significantly different at P<0.05, according to the DMRT.

Table 2. Influence of artificial light sources [fluorescent lamp (FL), bar-light-emitting diode (bar-LED) and bulb-light-emitting diode (bulb-LED)] on leaf area (LA), total LA, leaf number (LN), shoot fresh mass (FM), root FM, total FM, shoot dry mass (DM), root DM, total DM, shoot/root (S/R) ratio FW, shoot/root (S/R) ratio DW, water content (WC), specific leaf area (SLA), leaf dry matter content (LDMC), and leaf thickness (LT) in green oak lettuce. Pattani, Prince of Songkla University, 2018.

Light source parameters		FL	Bulb-LED	Bar-LED
LA (cm^2)		5.45 ± 1.20b	14.66 ± 3.42a	13.34 ± 3.30a
Total LA (cm^2)		85.03 ± 23.44b	256.64 ± 88.00a	230.95 ± 68.43a
LN (leaves)		15.47 ± 2.16b	17.60 ± 3.04a	17.33 ± 2.25ab
FM (g)	Shoot	6.40 ± 1.57b	26.63 ± 10.15a	26.89 ± 5.58a
	Root	1.51 ± 0.33b	5.84 ± 2.15a	6.08 ± 1.21a
	Total FW	7.91 ± 1.63b	32.47 ± 11.73a	32.96 ± 6.09a
DM (g)	Shoot	0.38 ± 0.09b	1.40 ± 0.48a	1.57 ± 0.24a
	Root	0.27 ± 0.02b	0.55 ± 0.13a	0.56 ± 0.08a
	Total DW	0.65 ± 0.09b	1.95 ± 0.58a	2.13 ± 0.27a
S/R ratio	FW	4.37 ± 1.22a	4.82 ± 1.97a	4.54 ± 1.08a
	DW	1.40 ± 0.06b	2.62 ± 0.18a	2.70 ± 0.18a
WC (mL)		6.02 ± 1.52b	25.23 ± 11.22a	25.32 ± 5.48a
SLA (m^2 kg^{-1})		129.19 ± 33.63b	182.40 ± 105.74a	118.66 ± 41.61b
LDMC (mg g^{-1})		0.05 ± 0.01a	0.06 ± 0.01a	0.06 ± 0.01a
LT (μm)		0.13 ± 0.04a	0.13 ± 0.06a	0.17 ± 0.08a

Mean ± SD values followed by a different letter in the same row are significantly different at P<0.05, according to the DMRT.

significantly higher when grown under a combination of red and blue than under white LED light (Zhang *et al*., 2018). Lin *et al*. (2013) reported that shoot DW and FW of lettuce were the greatest when grown under red + blue + white LED at 15 days after sowing, and additionally the shoot FW of lettuce treated with red + blue + white LED was significantly increased by 10% compared to the FL control.

Bulb-LED consumed the least electrical power per lamp followed by FL and Bar-LED, but the number of lamps per plots differs by type of lamp (Table 3). Power consumption per plot was the highest for FL followed by bulb-LED and bar-LED, similar to the ranking of power consumption per area. Consequently, bar-LED had the least power consumption per plot or cultivated area, followed by bulb-LED that was comparable with FL (Table 3). For the power consumption, bar-LED was the lowest, however, its quality of light was the best match with plant photosynthesis, growth and development, as shown in Table 1. The bulb-LED consumed less power than FL, but it had better light quality in terms of PPFD-B, PPFD-R, and the color ratio of B and R.

Phytochemicals, nitrate and chlorophyll contents

This experiment showed that ascorbic acid content was not statistically significant between the treatments (Figure 1B). However, Chen *et al*. (2011) established that ascorbic acid contents of lettuce were higher when grown under blue LED light or a mixture of red and blue LED lights than under only red LED light.

The TPC results are shown in Figure 1B. The lettuce plants were found to have various phenolic levels, ranging from 0.14 to 0.22 mg GAE g^{-1} extract. Lighting with bar-LED gave significantly highest content of TPC (0.22 mg GAE g^{-1} extract) followed by bulb-LED (0.14 mg GAE g^{-1} extract) and FL (0.14 mg GAE g^{-1} extract). Li & Kubota (2009) have described that light affects the accumulation of phenolic compounds in plants, especially red light.

The antioxidant capacities are

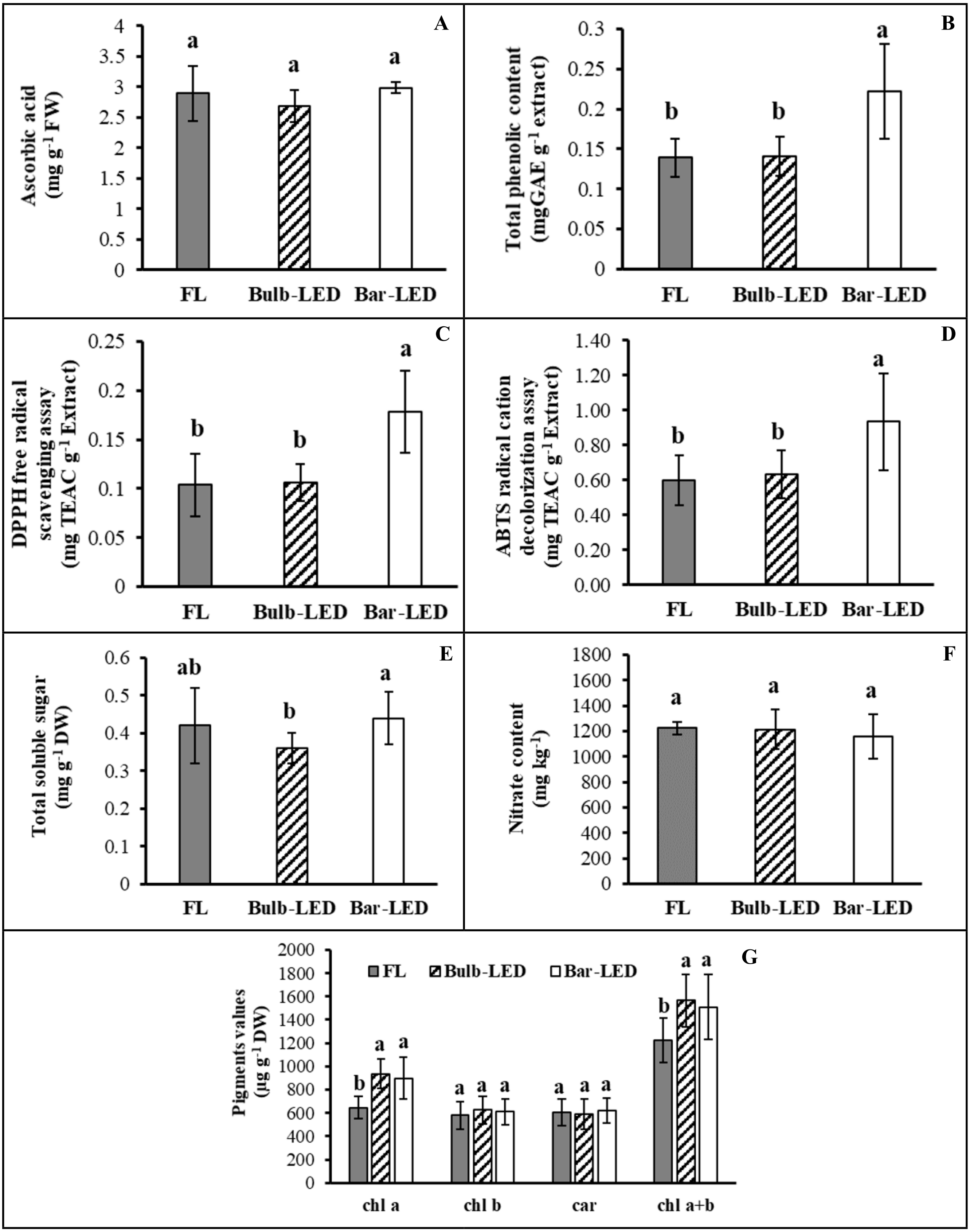

Figure 1. Ascorbic acid content (A), total phenolic content (TPC) (B), 2,2-diphenylpicrylhydrazyl (DPPH) (C), 2,2'-azino-bis (3-ethylbenzthiazoline-6-sulphonic acid) (ABTS) (D), total soluble sugar content (TSSC) (E), nitrate content (F), chlorophyll (ch *a*, chl *b* and chl a+*b*) and carotenoid (car) contents (G) of green oak lettuce grown under the artificial light sources [fluorescent lamp (FL), bar-light-emitting diode (bar-LED) and bulb-light-emitting diode (bulb-LED)]. Different letters in one column plot indicate significant differences at the 95% level, according to the DMRT (n= 9), and the bars represent the standard deviations. Pattani, Prince of Songkla University, 2018.

Table 3. Shoot fresh mass (FM), shoot dry mass (DM) production per mole and power consumption of artificial light sources [fluorescent lamp (FL), bar-light-emitting diode (bar-LED) and bulb-light-emitting diode (bulb-LED)] for green oak lettuce. Pattani, Prince of Songkla University, 2018.

Light source parameters	FL	Bulb-LED	Bar-LED
FM per mole of artificial lighting (g mole^{-1} m^{-2})	1.33 ± 0.12b	1.33 ± 0.12b	1.78 ± 0.25a
DM produced by artificial lighting (g m^{-2})	22.95 ± 3.85b	65.10 ± 8.24a	79.93 ± 4.62a
DM per mole of artificial lighting (g mole^{-1} m^{-2})	0.10 ± 0.02c	0.31 ± 0.04b	0.36 ± 0.02a
Power consumption (W)	18	4	30
Number of lamps plot^{-1*}	3	12	1
Power consumption plot^{-1} (W)	54	48	30
Power consumption m^{-2} (W m^{-2})	168.75	150.00	93.75
Power savings compared with FL (%)	0.00	11.10	44.40

*Each plot was 3,200 cm^2. Mean ± SD values followed by a different letter in the same row are significantly different at P<0.05, according to the DMRT.

shown in Figure 1C and D. The highest antioxidant capacities were detected for plants grown under bar-LED, both in the DPPH assay (0.18 mg trolox equivalent antioxidant capacity (TEAC) g^{-1} extract) (Figure 1C) and in the ABTS assay (0.93 mg TEAC g^{-1} extract) (Figure 1D). There was no significant difference between antioxidant capacity in plants grown under FL (ABTS 0.60 mg TEAC g^{-1} extract and DPPH 0.10 mg TEAC g^{-1} extract) and Bulb-LED (ABTS 0.63 mg TEAC g^{-1} extract and DPPH 0.11 mg TEAC g^{-1} extract). Among the artificial light sources, bar-LED induced the highest antioxidant capacity to lettuce in terms of both ABTS and DPPH scavenging activities. This result may be due to bar-LED inducing the highest TPC antioxidant levels. However, the plant sourced antioxidant, including ascorbic acid, and carotenoids (Figure 1G) did not significantly differ between the treatments. Therefore, TPC played a major role in determining the antioxidant capacity because both assays are highly related to TPC (Johari & Khong, 2019).

TSSC was significantly highest in plants grown under bar-LED followed by FL and bulb-LED (0.44, 0.42 and 0.36 mg g^{-1} DW, respectively) that were mutually comparable, as shown in Figure 1E. Several studies have confirmed that red LED light induces higher TSSC levels, for example, in the seedlings of cucumber, tomato (Cui *et al*., 2009), and radish (Zhang *et al*., 2010). Lin *et al*. (2018) found that TSSC in lettuce plants was higher with R:G:B = 7:0:3 (PPFD = 150 μmol·m^{-2}·s^{-1}) than with FL (150 μmol·m^{-2}·s^{-1}) lighting.

Plants grown under FL, Bulb-LED and Bar-LED showed the nitrate content as following 1223, 1211 and 1157 mg kg^{-1}, respectively. Nevertheless, there was no significant difference among the treatments on nitrate content. However, high levels of nitrate in vegetables may be a risk to human health. Therefore, the Food and Agricultural Organization and the World Health Organization suggested that the acceptable nitrate content in daily lettuce consumption should not exceed 3,000 mg kg^{-1}. The nitrate contents in lettuce plants grown under artificial light sources (bar-LED, bulb-LED and FL) were in the range 1211-1157 mg kg^{-1}, therefore these were safe for daily consumption in terms of nitrate.

The contents of chlorophyll *a* and chlorophyll *a* + *b* in plants grown under bar-LED (897.89 and 1508.56 μg g^{-1} DW, respectively) and bulb-LED (937.17 and 1564.12 μg g^{-1} DW) were significantly higher than in plants grown under FL (646.70 and 1226.93 μg g^{-1} DW) (Figure 1G). However, there was no difference in the contents of chlorophyll *b* (580.24, 626.95 and 610.67 μg g^{-1} DW, respectively) and carotenoids (602.63, 591.14 and 621.05 μg g^{-1} DW, respectively) among the treatments (Figure 1G). The chlorophylls are the major pigments absorbing blue (420-450 nm) and red (600-700 nm) light for plant photosynthesis. However, chlorophyll *a* absorbs at 430 nm and 665 nm peaks while chlorophyll *b* absorbs at 453 nm and 642 nm (Sager & McFarlane, 1997). Our results show that plants grown under bar-LED and bulb-LED had significantly higher chlorophyll *a* and chlorophyll *a* + *b* contents than plants grown under FL.

In conclusion, the bar-LED was better than bulb-LED or FL in having the least energy consumption and the best light quality parameters of PAR, PPFD, PPFD-B, PPFD-R, YPFD, and color of R. Moreover, highest concentration of TPC and plants grown under bar-LED and bulb-LED had larger FW, DW, LA, LN, chlorophyll *a* and chlorophyll *a* + *b*, than plants grown under FL. Thus, the results suggested that bar-LED which have spectrum ratio of 1 (460 nm) : 1 (630 nm) : 1 (660 nm) could apply in a controlled environment of vegetable production, as it can increase growth production and accumulation of some phytochemicals, especially TPC, improve antioxidant activity and highest energy saving.

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