GROWTH AND YIELD OF ORGANIC *LACTUCA SATIVA* CV. FIRE RED UNDER IRRADIATION OF LIGHT EMITTING DIODE IN CONTROLLED ENVIRONMENT

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ABSTRACT

Light emitting diode (LED) has recently been studied for indoor vegetable and ornamental crop production. It is of lower energy consumption and emits lower heat as compared to conventional lamps used for the same purposes. It is also found to repel insects and hence, can be of great benefits to crop production by reducing insect pest problems. However, LED provides narrow range of light spectrum. Many studies have, therefore, been conducted to explore the suitable spectral regions for rapid growth of specific crops, especially the high value crops, under controlled conditions. The current study was carried out to evaluate the effects of irradiation in terms of monochromic red (660 nm) and blue (450 nm) LED, applied singly or in combination, combined with varying photoperiods on growth and yield of Lactuca sativa cv. Fire Red in air-conditioned laboratory of 25±2 °C and relative humidity of 55±5%. It is a high value leafy vegetable with attractive red pigmentation commonly consumed raw as salad. Seedlings at one week after germination in moist jiffy blocks, having height of approximately 5 cm, were transferred to PVC troughs of 5 cm in diameter containing compost tea of 450±50 µS at pH 6.5-7.5. Plants were grown at a distance of approximately 15 cm below LED of 18W 240V. Monochromic red LED was not appropriate for growing this vegetable while plants irradiated with monochromic blue LED were the biggest in terms of plant height and fresh weight at seven weeks after sowing, but the plant had the lowest number of leaves. The leaves were also loosely arranged and had less red pigmentation when grown under monochromic blue LED. Photoperiod ranging from 12 to 18 h did not result in great difference in growth of this vegetable. Combined red and blue LED at 2:1 or 1:2 ratios yielded more compact vegetable with more red pigmentation. Combinations of higher amount of blue light spectrum and less red light or that of other wavelengths are yet to be explored for optimal growth of this leafy vegetable.

Key words: monochromic light, photoperiod, compost tea, compact vegetable, indoor vegetable production

Introduction

Light is one of the environmental factors required by plants for growth and development. Supplemental light was introduced in the cultivation of plants. Many studies on artificial and conventional lighting for raising plants have been carried out but there is still a lot of unknown regarding the generalization or specific application of such lighting for plant production. Conventional lighting commonly used as supplemental lighting for greenhouses includes that provided by fluorescent, high-pressure sodium and metal halide lamps (Brazaitytė et al., 2006; Wheeler, 2008).

Vegetable and ornamental crop planting using supplemental light has recently been practised in the field or greenhouse for enhanced productivity. Quantitative and qualitative crop production can be significantly affected due to lack of light supply and uncertain climate. For example, plant production will drop during raining seasons following reduced sunshine period. Later, researchers found that cultivation of vegetables and ornamentals can be fully dependent on artificial light in the absence of natural light. Vegetables have been produced satisfactorily with conventional lamps under environment with controlled lighting, temperature and humidity. Production was found faster and high quality vegetables could also be obtained under controlled growth environment.

Light-emitting diodes (LEDs) are widely used later as they have low power consumption and little heat production. LEDs, however, produce narrow light spectrum and therefore, must be studied in detail to provide all essential light spectrum required for optimum plant growth (Massa et al., 2008; Morrow, 2008).

Red spectral region is essential for photosynthetic apparatus and it also influences the transport of assimilates even though the physiological responses to spectral changes can differ among plant species or varieties (Baroli et al., 2008; Poudel et al., 2008; Li et al., 2012). Plants also require blue light to perform photosynthesis, develop chloroplast and synthesize chlorophylls and some chemical compounds in plants (Heo et al., 2002; Hogewoning et al., 2010). Fukuda et al. (2011) reported that blue light also stimulated the shoot elongation and promoted flowering of *Petunia*. Nevertheless, some researchers revealed that a combination of red and blue was more efficient for growth of several crops (Schuerger et al, 1997; Kim et al., 2004; Samuoliene et al., 2010). Massa et al. (2008) mentioned that custom designed LEDs could also significantly reduce insect, disease or pathogen loads on certain crops.

In this study, *Lactuca sativa* cv. Fire Red was grown organically with hydroponic system using LED. This vegetable with attractive red pigmentation is one of the most significant crops in the world and greenhouse production (Fu et al., 2012). The aim of this study was to examine the combined effects of photoperiod and light quality in terms of spectral regions of blue and red, applied singly or in combination, towards growth, development and production of this vegetable in laboratory under controlled environment.

Material and Method

Location of Study

Compost and compost tea as the organic solution used for growing *L. sativa* were prepared in the media preparation area of Puncak Alam campus, Faculty of Plantation and Agrotechnology, Universiti Teknologi MARA (N 3°11.84', E 101°26.93'). Experiment on growth and production of *L. sativa* under LED was carried out in the air-conditioned laboratory of the faculty in the same campus. The average temperature and relative humidity of the laboratory were 25±2 °C and 55±5% respectively.

Compost Tea Preparation

Compost derived from dumped vegetables of Brassicaceae, fish refuse (gills and internal organs) and expired or dumped bread collected from kitchens of local restaurants at 3:1:2 was first prepared with 1 kg of cocopeat as bulking agent using an automated mini composter (IMP Organic, Malaysia). Raw materials of 1.5 to 2 kg were loaded into the composter at alternate days for a week until full level of the composter. Composting was fully carried out by only natural occurring microorganisms without any additional enzyme or microbial inoculant. Moisture for the microorganisms was dependent on the water within the raw materials and no water was added throughout the composting process. The three cylindrical bars in the composter turned automatically for 2 min at 30 min intervals to enhance growth of the population of microorganisms to perform the composting of the raw materials. The temperature indicator on the composter showed higher temperature but it had always been below 50 °C during composting procedure, indicating the active composting process carried out by the microorganisms. This allowed hormonal and enzymatic compounds of the raw materials remained undestroyed and can be of great benefit for enhancing healthy growth of plants.

After reaching full level of materials in the composter, the composting materials were let to partially mature for a week until the volume was reduced to half. Then, 1.5 to 2 kg raw materials as mentioned were loaded into composter at alternate days for a week until full level again. The composting materials were then allowed to mature in the next two to three weeks until the temperature indicator of the composter showed ambient temperature. The compost was then removed from the composter and sun dried, followed by sealing in plastic bags to avoid compost from absorbing moisture from the air until use.

Compost tea was prepared when seeds of *L. sativa* were sown for experimentation. Compost of 1 kg was placed in a bucket and 10 litres tap water were added into the bucket. The end of the aeration tube connected to an aquarium pump was tied to a piece of stone and placed at the bottom of the mixture of compost and water. Aeration was carried out for 48 h to produce compost tea. Mixture was then filtered using a piece of cloth and the filtrate was the compost tea used for growing organic *L. sativa* in this study. The procedure was repeated and a total of 20 litres compost tea were prepared for this study.

Test Material

Lactuca sativa cv. Fire Red seeds were purchased from a local vegetable seed supplier. The seeds were germinated in jiffy blocks moistened with tap water under monochromic red LED (660 nm) in air-conditioned laboratory as mentioned. This light wavelength was chosen for seed germination as it was found the best for this purpose with some earlier trials. Seedlings at one week after sowing, having height of approximately 5 cm, were then transferred to the PVC troughs for experimentation.

Experimental Procedure

Seedlings in PVC troughs of 110 cm in length and 5 cm in diameter were grown at 15 cm apart at different photoperiods under LED of monochromic blue (450 nm) and red at different ratios in the same air-conditioned laboratory. LED lightings used in this study were 18W 240V. This experiment was laid out based on a split plot design. The photoperiods studied of 12, 15 and 18 h were main plots using three four-tier wooden racks. Within each main plot (rack), red LED (R), blue LED (B), combined blue and red LED at 1:2 (2RB) and 2:1 (2BR) respectively were sub plots, each occupying a level (tier) of each rack at random. Every level of each rack was covered with blackout cloth at all sides to ensure the plants in each level received only the assigned wavelength of light. Each treatment was replicated six times, each with a single plant.

Lactuca sativa seedlings were grown hydroponically in PVC troughs as mentioned for six weeks. Seedlings were irradiated at a distance of approximately 5 cm from LED and the position of LED was adjusted accordingly as the plants grew taller and bigger. The troughs were filled with 1.5 litres compost tea diluted to 450±50 µS with tap water. pH of the diluted compost tea ranged from 6.5 to 7.5. EC and pH of the solution in troughs were checked twice weekly and adjusted accordingly when necessary.

Troughs were also added with diluted compost tea accordingly when the solution level dropped to below 2 cm. There was no other fertilizer applied throughout the experiment.

Data Collection

Height, number of leaves and red pigmentation of each plant were recorded weekly. Height was measured from root collar to the highest level of the plant in its own form and appearance as affected by photoperiod and LED spectrum. Leaves with length of ≥ 1 cm were counted as number of leaves. At seven weeks after sowing, all plants were cut at the root collar. Fresh weight of each whole plant was weighed using an analytical balance.

Experimental Design and Statistical Analysis

This study was carried out based on a split plot design as mentioned. Data collected were subjected to analysis of variance (ANOVA) and means were compared using Tukey's Honestly Significant Difference (HSD) test at 5% level of significance.

Results

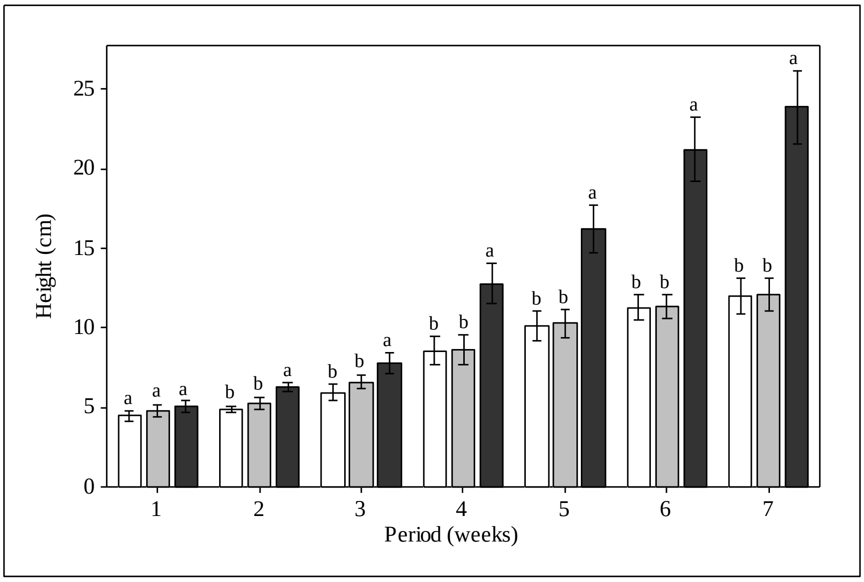
At absence of natural light, monochromic 660 nm (R) failed to grow *L. sativa* cv Fire Red. The plants elongated with thin but long green yellowish leaves under R for about three weeks and they died at four weeks after sowing. Other LED treatments significantly affected plant height throughout the study period of seven weeks (Table 1; Figure 1). Plants grown under monochromic 450 nm (B) were obviously taller than those irradiated with 2BR or 2RB by four weeks after sowing. Growth of plants in terms of height continued to increase obviously thereafter. At the end of the study period, B produced plants with height double of those grown with 2BR or 2RB. Meanwhile, the photoperiods of 12, 15 and 18 h generally did not give great influence on plant height growth, except those raised with 18 h photoperiod were significantly taller plants by the end of the study at seven weeks after sowing (Table 2). There was also generally no significant interaction between photoperiod and light spectrum in determining the plant height growth under the controlled environment as studied.

Table 1: F-value for variables affecting plant height

Variable	Period (weeks after sowing)						
	1	2	3	4	5	6	7
Replicate	0.63^{ns}	1.00^{ns}	1.03^{ns}	2.01^{ns}	1.26^{ns}	2.60^{ns}	1.94^{ns}
Photoperiod	4.89^{*}	0.35^{ns}	0.19^{ns}	3.15^{ns}	2.25^{ns}	1.87^{ns}	4.81^{*}
Replicate x Photoperiod	0.81^{ns}	0.90^{ns}	1.19^{ns}	1.33^{ns}	1.72^{ns}	1.14^{ns}	1.41^{ns}
LED	2.98^{ns}	24.36^{***}	16.17^{***}	33.53^{***}	56.14^{***}	104.78^{***}	125.89^{***}
Photoperiod x LED	1.39^{ns}	0.85^{ns}	4.12^{**}	1.02^{ns}	0.81^{ns}	0.68^{ns}	1.80^{ns}

ns, *, **, *** indicate no significant difference, significant difference at 5%, 1% and 0.1% level of significance respectively.

Figure 1: Plant height as affected by light spectrum



, , indicate 2BR, 2RB and B respectively, means having same letter within each period are not significantly different at 5% level of significance.

Table 2: Plant height at seven weeks after sowing as affected by photoperiod

Photoperiod (h)	Plant height (cm)
12	14.28^{b}
15	16.36^{ab}

18	17.39 [a]

Means having the same letter are not significantly different at 5% level of significance.

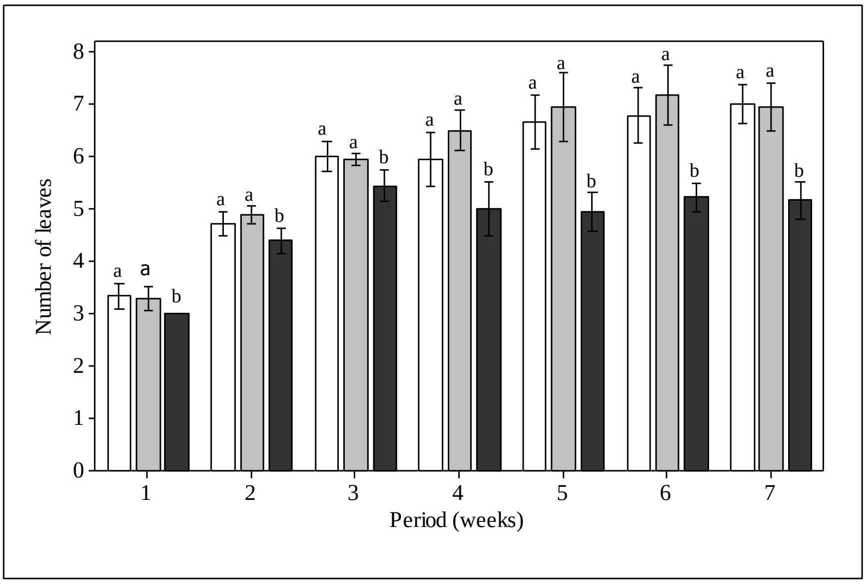
Table 3: F-value for variables affecting number of leaves

Variable	Period (weeks after sowing)						
	1	2	3	4	5	6	7
Replicate	1.00[ns]	0.86[ns]	0.93[ns]	1.11[ns]	1.99[ns]	3.53[*]	0.52[ns]
Photoperiod	121.00[***]	1.43[ns]	3.18[ns]	3.64[ns]	7.83[**]	17.22[***]	3.59[ns]
Replicate x Photoperiod	1.00[ns]	0.98[ns]	0.66[ns]	0.71[ns]	0.63[ns]	0.69[ns]	3.67[**]
LED	31.00[***]	7.33[*]	6.79[*]	10.35[***]	20.75[***]	32.77[***]	66.90[***]
Photoperiod x LED	31.00[***]	3.49[*]	2.54[ns]	0.32[ns]	0.62[ns]	1.90[ns]	2.91[*]

ns, *, **, *** indicate no significant difference, significant difference at 5%, 1% and 0.1% level of significance respectively.

Light spectrum was also the main determinant of the development of leaves in *L. sativa* irradiated by LED (Table 3). In contrast to plant height, monochromic 450 nm (B) was the least efficient for leaf number gain in this leafy vegetable (Figure 2). This irradiation treatment also reduced expression of red pigments on the leaves. On the other hand, both 2BR and 2RB treatments enabled this vegetable to develop more leaves with more red pigmentation throughout the study period. Photoperiods as studied did not indicate its obvious role in enhancing the development of leaves while significant interaction between photoperiod and light spectrum at end of the study at seven weeks after sowing again indicated that B was the main attribute for lower number of leaves in this vegetable (Tables 3 and 4). In fact, B played a role only in growth of this plant in terms of length of leaves contributing to significantly taller plants but the leaves were loosely developed while combination with red light in the treatments of 2BR and 2RB enabled development of more compacted plants with more leaves at a lower plant height gain.

Figure 2: Number of leaves as affected by light spectrum



indicate 2BR, 2RB and B respectively, means having same letter within each period are not significantly different at 5% level of significance.

Table 4: Plant leaf number at seven weeks after sowing as affected by interaction of photoperiod and light spectrum

Photoperiod (h)	LED	Number of leaves
12	2BR	7.50 [a]
	2RB	7.83 [a]
	B	5.33 [c]
15	2BR	6.83 [ab]
	2RB	6.17 [bc]
	B	5.00 [c]
18	2BR	6.67 [ab]
	2RB	6.83 [ab]
	B	5.17 [c]

Means having the same letter are not significantly different at 5% level of significance.

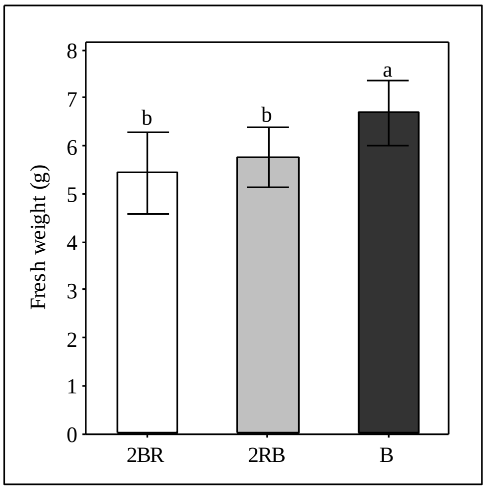
Fresh weight at harvest as the main parameter of production of this vegetable was also significantly determined by only light spectrum (Table 5; Figure 3). Plant height seemed to contribute more to the fresh weight of the plant as compared to number of leaves as plants raised under B had significantly the highest fresh weight. Photoperiod and interaction between photoperiod and light spectrum ultimately did not have significant effects on the plant fresh weight (Table 5).

Table 5: F-value for variables affecting fresh weight

Variable	Fresh weight
Replicate	5.25*
Photoperiod	0.51ns
Replicate x Photoperiod	1.64ns
LED	6.66**
Photoperiod x LED	1.06ns

ns, ** indicate no significant difference and significant difference at 1% level of significance respectively.

Figure 3: Fresh weight as affected by different light spectrum



Means having the same letter are not significantly different at 5% level of significance.

Discussion

LED at monochromic 450 nm (B) was capable for growing *L. sativa* cv Fire Red under indoor or laboratory condition. Some researchers stressed that combinations of blue and red spectral regions were the best for plants and vegetables (Yorio et al., 2001; Ohashi et al., 2007; Domurath et al., 2012; Gonzalez, 2012). Gonzalez (2012) found that combination of 23% blue light and 77% red light gave excellent results for optimum plant growth as monochromic blue causes lower yield of photosynthesis. LED of blue light spectrum was also reported to inhibit the elongation of stem in some plant species as compared to high pressure sodium lamps (Johkan et al., 2010; Islam et al., 2012). Nevertheless, Gautam et al. (2015) reported an opposite trend with *Petunia*; the plant exposed to an additional blue light had increased shoot length as compared to that resulted by monochromic red light. *Sesamum indicum* also showed rapid stem elongation under blue LED, indicating that this light wavelength possibly has a strong stimulating effect on stem development, but its leaf growth was suppressed under blue light (Hata et al., 2013). Blue LED also resulted in best fresh weight gain in *L. sativa* Summer Surge (Shimokawa et al., 2014). These researchers suggested that blue light affects photosynthetic efficiency of this vegetable.

The current study and previous studies suggested that LED could be a useful and cost effective lightning source or supplement for indoor cultivation of *L. sativa*. Despite monochromic blue spectrum was the best for growth of *L. sativa* cv Fire Red in terms of size and fresh weight, it produced loose vegetable with less red pigmentation, which is of lower marketable value. Combination of blue and red light in ratios >2:1 may be attempted for this indoor vegetable cultivation.

Conclusion

LED of monochromic 450 nm (B) applied for 12 h is most cost effective in terms of fresh weight gain for *L. sativa* cv Fire Red under controlled environment in laboratory at full absence of natural light. Further studies on the application of precise light wavelength for this purpose is necessary for production of this variety of vegetable with more compacted appearance and red pigmentation. Study on the cost effectiveness, mainly expressed as reduced production period, is also important in recommendation of the application of LED for vegetable production.

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