The effect of light emitting diode (LED) spectrum and light duration on growth and yield of *Brassica sinensis L.* grown on floating raft hydroponic system

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Abstract. Recent technology in agriculture allows vegetable cultivation in controlled environment by utilizing energy derived from an artificial lighting. Light Emitting Diodes (LED) is a source of artificial light which produce light with the wavelength ranged from ultraviolet - 100 nm to infrared - 3,000 nm. Under natural or artificial lighting condition, plants require energy for photosynthesis from light between 380 nm to 700 nm. In this study we examined the use of two types of 45-watt LED (red and blue – C1, full spectrum – C2) with three different light durations (12 h – D1, 16 h – D2, and 18 h – D3) on the growth and yield performance of brassica under hydroponic technique. Research result showed that full spectrum LED provided better performance in plant height, leaves number and width, fresh yield, root length, and biomass in all combinations with light duration as compared to red and blue LED. The combination of full spectrum LEDs with a duration of 16 h showed the best fresh yield (3.96 kg m^{-2}) followed by 18 h (3.57 kg m^{-2}) and 12 h (3.22 kg m^{-2}). Although the highest production was resulted from the combination of full spectrum LED and 16 h light duration, the most efficient in electric energy utilization was showed in the combination of full spectrum LED and 12 h light duration. All in all, we concluded that the use of full spectrum LED in combination with 16 h light duration feasible to be implemented in brassica cultivation under controlled environment.

1 Introduction

Recent technology in agriculture allows vegetable cultivation in controlled environment by utilizing energy derived from artificial lighting. Indoor farming systems equipped with artificial lighting provide specific potential for efficient use of water for food production [1]. A Photosynthetic Photon Flux Density (PPFD) of 250 μmol m^{-2} s^{-1} seems suitable for optimizing yield and resource use efficiency in red and blue Light Emitting Diodes (LED) lighting for indoor cultivation of lettuce and basil under the prevailing conditions of the used indoor farming set-up [2]. Optimization of light, both quantity (intensity and duration

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of irradiation) and quality (wavelength) in indoor plant cultivation was the main parameter [3] [4] [5].

In indoor cultivation, it was possible to use artificial light such as LED. LED is a source of artificial light which produce light with the wavelength ranged from ultraviolet – 100 nm to infrared – 3,000 nm. Under natural or artificial lighting condition, plants require energy for photosynthesis from light between 380 nm to 700 nm. LED Red and blue were able to increase biomass and photosynthesis [6]. One cultivation method that can be applied to indoor cultivation is a hydroponic system [7].

Hydroponic systems provide an increased photosynthetic efficiency using light cooling and indoor environment and the possibility of transpiration water recovery through air dehumidification, while indoor farming can increase water use efficiency by up to 50 times compared to current greenhouse systems [8]. Floating raft hydroponic system was a hydroponic system by cultivating plants in Styrofoam box holes that float on the surface of the nutrient solution [9]. Some of the advantages of this system are more crop production, faster plant growth, more efficient use of fertilizer, more efficient use of water, less labor required, cleaner work environment, more precise control of water, nutrients and pH, and can reduce pest and disease problems in plants [10] .

Previous research on the use of LEDs has been carried out but is still limited to the use of LED red, LED blue and LED green types, as well as on the duration of irradiation which is limited to 12 to 16 hours. Suitable plants developed with a hydroponic system that requires lighting 12-16 h per day were brassica. So, in this study we examined the use of two types of 45-watt LED (red and blue – C1, full spectrum – C2) with three different light durations (12 h – D1, 16 h – D2, and 18 h – D3) on the growth and yield performance of brassica under hydroponic technique. The purpose of this study was to determine the effect of the use of LED type on lighting duration on growth and yield performance of brassica under hydroponic technique.

2 Materials and methods

2.1 Materials

The equipment used in this study was a set of floating raft hydroponic system, LED full spectrum, LED red blue, oven, thermometer, thermos-hygrometer, water quality tester, lux meter, pH meter, and other supporting equipment. The floating raft hydroponic system used was a planting tub with nine planting holes. The planting tub was arranged according to the criteria in Fig. 1 using an iron rack equipped with LEDs as lighting in accordance with these criteria. The materials used in the form of Brassica seeds, AB mixes nutrients, and other supporting ingredients.

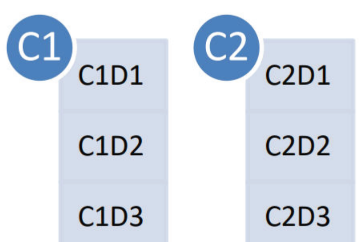

Fig. 1. Arrangement of laying the planter tub in the growth chamber.

2.2 Methods

The treatment carried out was by comparing the use of two types of light spectrum (LED red and blue - C1, LED full spectrum - C2) with three different light durations (12 h - D1, 16 h - D2, and 18 h - D3) on the growth and yield power of brassica plants. Variations of treatment carried out in the form of C1D1, C1D2, C1D3, C2D1, C2D2 and C2D3.

The observation variables carried out were observations of growing environmental conditions, plant growth, and plant yields. Observed variables for the growing environment include observations of light intensity, air temperature, relative humidity (RH), total dissolved solids (TDS), and nutrient pH. Plant growth observation was carried out by measuring plant height, number of leaves, and leaf width. Variable observation of plant yields was recorded in the form of fresh weight of plants, length of roots, and dry weight of plants.

Table 1. Observation procedure.

Variable	Instrument	Time	Repeat/ Sample
Light intensity	Lux meter	Every day on 1^{st} DAS – 21 DAS at 08.00 and 17.00 WIB	5
TDS	Water quality tester		
pH	pH Meter		
Air temperature	Termohigrograf	Every day on 1^{st} DAS – 21^{st} DAS at 08.00, 13.00 and 17.00 WIB	
RH			
Plant height	Caliper	Every three days on 3^{rd} DAS – 21^{st} DAS	9 each treatment
Number of leaves	-		
Leaf width	Caliper and ruler		
Length of roots		At harvest	
Fresh yield	Digital scales		
Biomass			

The observed variables were adjusted according to Table 1. Observations of the growing environment such as light intensity, TDS, and pH are carried out every day at 08.00 and 17.00 WIB while air temperature and RH at 08.00, 13.00, and 17.00. This observation was made to show the growing environmental conditions of brassica plants. Plant growth observations such as plant height, width and number of leaves are carried out every three days during the plant growth process, while plant yields were observed during harvesting. Fresh yield was observed by weighing the fresh weight of plants after harvest in each treatment, while biomass is observed by drying, aerating all parts of the plant until wilted, then putting it in the oven for ±24 hours with a temperature of 80°C, then weighing the weight.

2.3 Energy consumption analysis

Energy consumption analysis was carried out by calculating the cost of using artificial light energy in each yield treatment per area of brassica obtained. The calculation of unit area production can use equation (1), the calculation of electrical energy consumption can use equation (2) and the calculation of energy consumption cost can use equation (3).

$$Y_A = \frac{\sum y}{A} \tag{1}$$

$$W = \frac{P \times t}{6 \times 10^4} \tag{2}$$

$$B = \frac{W \times c}{Y_A} \tag{3}$$

Y_A	: Production per area (kg/m^2)	t	: light durations (hour)
$\sum y$	: Total Production (kg)	P	: Power (W)
A	: Area (m^2)	c	: Cost of electrical energy (Rp/kWh)
W	: Electrical energy consumption (kWh)	B	: Cost of energy consumption (Rp/kgm^2).

3 Results and discussion

3.1 Environmental conditions of plant growing

Light was one of the important factors affecting plant growth and productivity, light was required in the light reaction (LDR) and Calvin cycle (LIR) [11]. The higher the intensity of light produced by LED grow light, the greater the weight of the roots produced [12]. The light observed in this study using Red and blue LED – C1 has a value of 4,385 lux while for full spectrum LED – C2 has a value of 16,350 lux.

Brassica can grow well in air temperatures ranging from 15^o – 30^{o}C [13] and the growth of brassica flowers was not optimal at temperatures more than 30^{o}C [14]. The optimal RH of brassica ranges from 70 – 90%, because when the RH was at that value stomata can open and absorb carbon dioxide optimally [14]. The measured ambient temperature has a relatively stable value ranging from 25.4^o – 26.8 ^{o}C while RH ranges from 73.8 – 78.6 %. In this study, the temperature and RH of the environment were conditioned to be stable using an air conditioner (AC). The value obtained in this study is in optimal conditions so that it can be stated that air temperature and RH were in optimal conditions to support the growth and development of brassica.

Table 2. TDS and pH value of nutrient solution.

Treatment	TDS (ppm)	pH
C1D1	987	5.7
C1D2	981	5.6
C1D3	970	5.8
C2D1	976	5.7
C2D2	963	5.7
C2D3	959	5.8

The total dissolved solids and pH of the nutrients used have values as presented in Table 2. Based on the data presented, the pH condition of the solution was maintained stable around 5.6 – 5.8 at each treatment given, this is in accordance with the statement of Edi & Bobihoe [15] which states that brassica plants will grow optimally at pH ranging from 5.5 – 6.5. Meanwhile, the concentration value of the solution represented by the TDS value was also in stable conditions around 957 – 987 ppm. Based on the data obtained for environmental factors, temperature, RH, TDS, and pH were conditioned in a stable state, this was done so that the treatment (light factor) alone has more influence on plant growth.

3.2 The effect of treatment on plant growth

Observation of plant growth was performed in the form of plant height, number of leaves and leaf width. The height of Brassica plants was measured from the base of the stem to the tip of the leaf. Measurements were taken every three days. Fig. 2 provides information that the light spectrum treatment obtained by lighting using full spectrum – C2 has a greater value in each light duration treatment for plant height factors. Plant height was the easiest growth indicator to measure. The speed of stem elongation varies by species and is influenced by the environment in which the plant grows. The growth of stem height was influenced by internal and external factors. The internal factor was hereditary. External factors come from the environment, namely temperature and light intensity [16]. Light intensity was an important factor that affects plant growth because it can interfere with the process of plant photosynthesis. C2 treatments were higher than C1 treatment occurs because the light received by C2 was greater than C1 so that the photosynthesis process experienced by brassica (C2) was much better than brassica (C1).

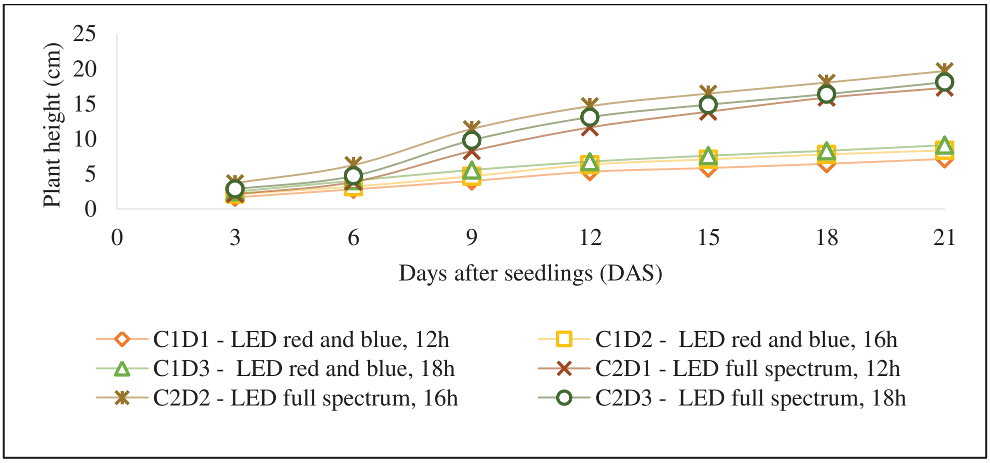

Fig. 2. Effects of treatment on plant height.

C2D2 treatment gives the highest plant height among other treatments. In addition to light intensity, lighting duration also affects plant growth, it is shown that D2 provides optimal lighting duration compared to other treatments so that C2D2 gets the best results. This was in line with Syach's research [17] which states that plants that lack light will cause the plant to grow faster but have a smaller biomass (etiolation) and will enter the death phase faster.

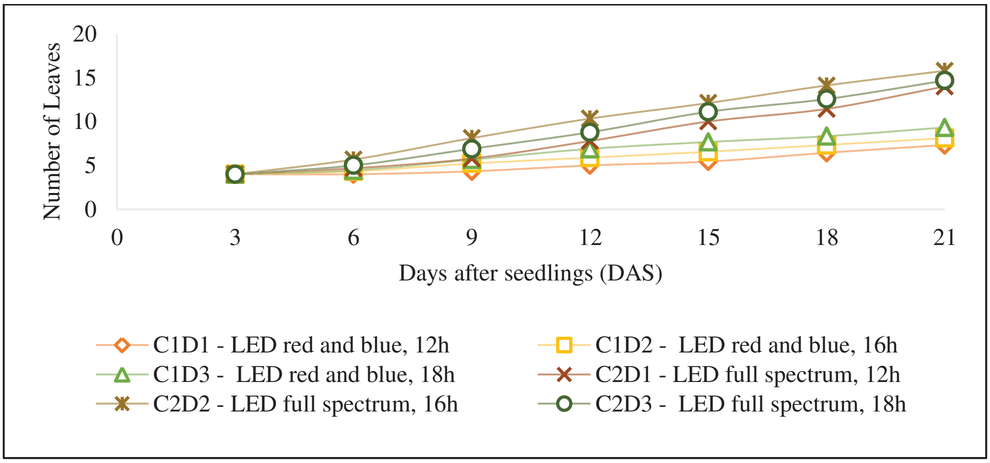

Fig. 3. Effects of treatment on number of leaves.

Fig. 3 showed data on the number of leaves against the treatment given. Based on the data obtained, there was an increase in the number of leaves every day. This shows that the use of LEDs as artificial light, supports the process of photosynthesis but the number of leaves in all C2 treatments is greater than in all C1 treatments. Meanwhile, the best number of leaves was found in the C2D2 treatment. These conditions were in line with the height of the plant. Light can affect photosynthesis based on light intensity, duration of irradiation, and light. The number of leaves can affect plant development, more leaves increase the process of photosynthesis because more light was captured [18].

Fig. 4 provides information stating the effect of light spectrum and light duration gives the highest width of leaves in C2D2 treatment compared to other treatments, this was in line with the plant height and number of leaves parameters. Based on the data obtained, the treatment given has an influence on plant growth parameters (plant height, number, and width of leaves). The best treatment was obtained at full spectrum treatment and light duration of 16 h (C2D2).

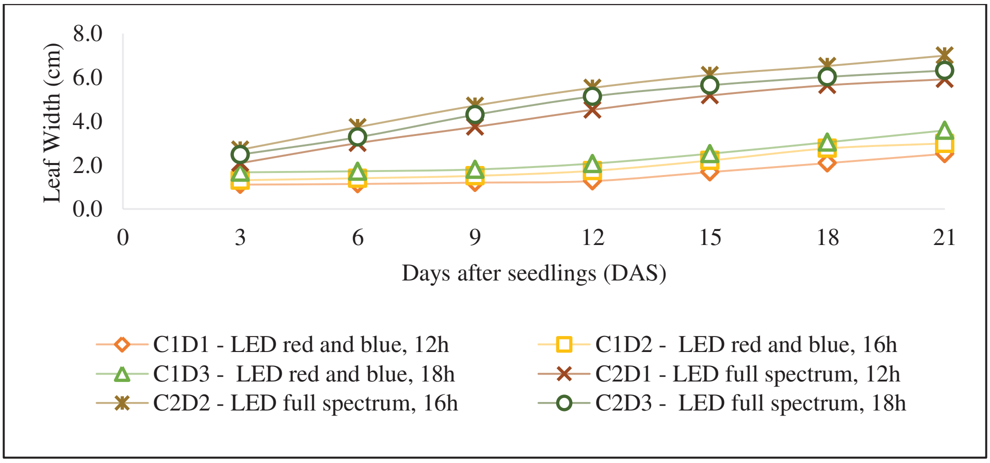

Fig. 4. Effects of treatment on leaf width.

3.3 The effect of treatment on root length, fresh yield, and biomass

Fig. 5 showed the results of full spectrum LED treatment giving higher values than red and blue LED treatment at all light duration. The greatest root length is obtained in C2D2 treatment. Light has an important role in the process of photosynthesis of plants. Light intensity, as well as good light quality can stimulate the growth of leaves which were the site of photosynthesis.

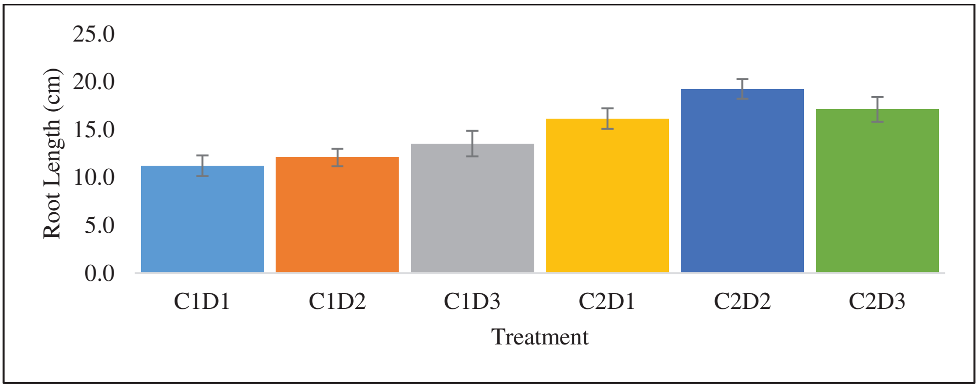

Fig. 5. Effects of treatment on average root length.

The more the plant has wide leaves, the better the roots of the plant. The process of photosynthesis can take place optimally so that food reserves can be translocated to all parts of the body including the roots so as to produce good root growth as well. The process of photosynthesis can take place optimally so that food reserves can be translocated to all parts of the body including the roots so as to produce good root growth as well [19].

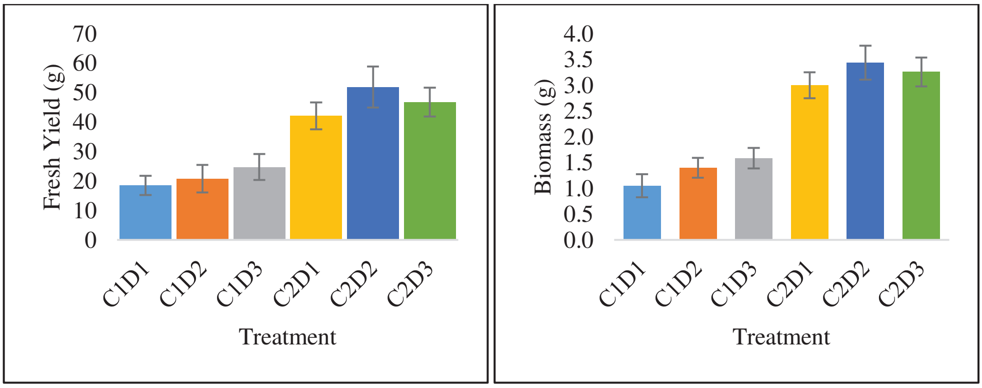

Fig. 6. Effects of treatment on average of fresh yield (a) and average of biomass (b).

The fresh weight of the plant was a parameter that plays a role in determining the quality of yield economically, especially in vegetable crop products such as brassica. The fresh weight of plants provides aggregated information about the growth, development and accretion of plant parts affected by moisture and nutrient content in plant tissue cells. The fresh weight also provides a related picture of plant height, number of leaves, leaf width and other plant parts [20]. Figure 6a showed the effect of full spectrum LED treatment giving higher values than red and blue LED treatment at all light duration and obtaining the best fresh weight in C2D2 treatment.

The dry weight of a plant is related to the height of the plant and the number of leaves of the plant. The dry weight of the plant was an indication of the success of plant growth because after the moisture content is removed, it will be known the results of clean photosynthesis will be known. Similar to the factor of fresh weight and root length, biomass obtained the best grades in C2D2 treatment and full-spectrum LED treatment gave better results than red and blue LED treatment at all light durations (Fig. 6b). In addition, the pattern produced from each treatment also gives the same pattern on the parameters of root length, fresh weight and biomass.

The average yield of dry weight of this plant and the average yield of fresh weight of this plant have to do with other parameters such as plant height, number of leaves, and leaf width. When related to the results of previous parameters, C2D2 treatment has the best results among other treatments in the parameters of plant height, number of leaves, and leaf width. So that the results of the previous parameters will also affect the average yield of dry weight, root length, and average fresh weight of plants. The growth of one part of the plant will be followed by the growth of other plant parts [21].

3.4 Energy consumption analysis

The use of LED full spectrum provides more efficient results in energy use for brassica production compared to the use of LED red and blue in each lighting duration treatment. Production per area in each treatment is presented in Fig. 7a. The highest production was found in the C2D2 treatment while the lowest production was in the C1D1 treatment.

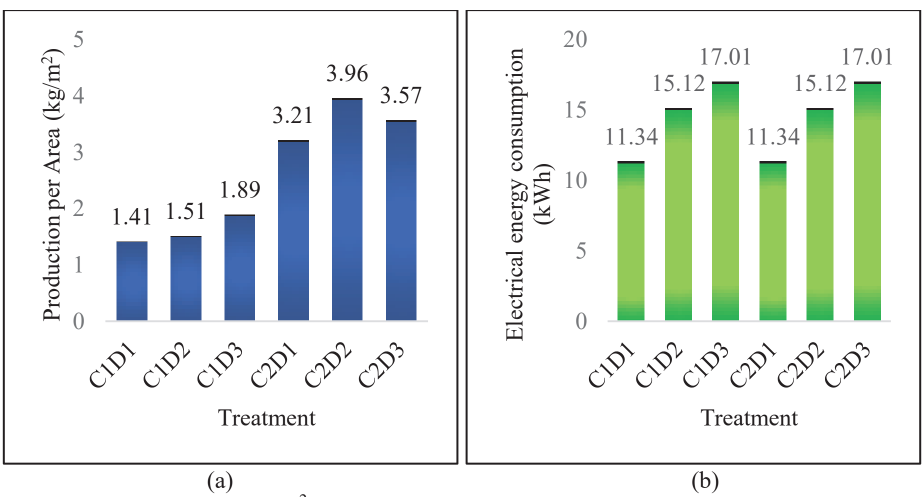

Fig. 8. Production per Area (kg/m^2) (a) and Electrical energy consumption (kWh) (b).

Fig. 7b showed the consumption of electrical energy used in each treatment. LED full spectrum and LED red and blue have the same power of 45-Watts, which distinguishes only the length of irradiation carried out so that the use of electrical energy will be the same when light duration was the same.

Production information per area and electrical energy consumption form the basis for energy consumption analysis. The amount of electricity tariff used in calculating the efficiency of electrical power consumption during observation was the tariff group for medium household needs with regular and prepaid electricity usage costs per kWh of Rp 1699.

Although each LED has the same power of 45 watts, there is a difference in efficiency in the use of electrical power. The difference is caused by the different intensity of light received and the light duration to the rate of photosynthesis. Fig. 8 showed the cost of energy consumption for each treatment. The use of LED full spectrum costs less than the use of LED red and blue in each treatment. Meanwhile, C2D1 treatment has the least cost compared to other treatments in the use of LED full spectrum.

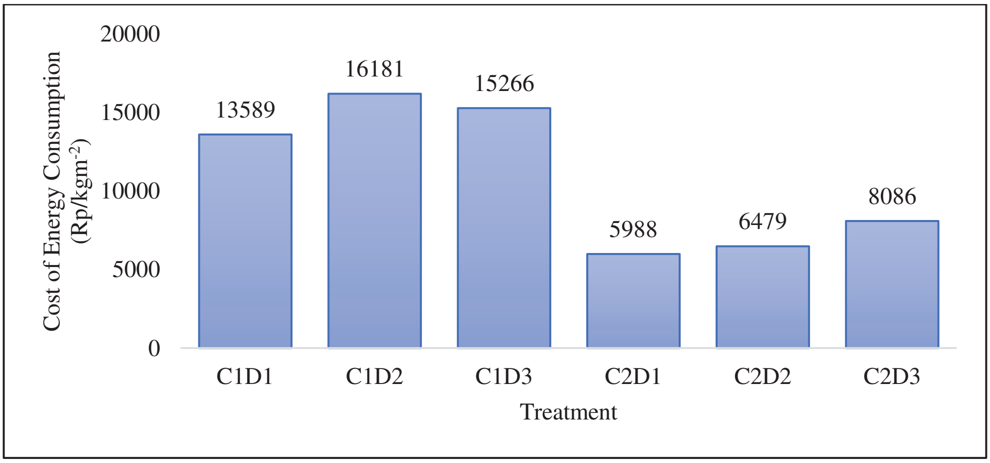

Fig. 8. Cost of energy consumption.

4 Conclusions

LED lighting treatment and light duration on the growth and yield of brassica plants using a floating raft system differ markedly on plant height, number of leaves, leaf width, fresh weight, root length, and biomass. Full spectrum LED - C2 treatment gives better results than red and blue LED - C1 on the growth and yield of brassica at all light duration treatments. The best results were obtained in the C2D2 treatment. All in all, we concluded that the use of full spectrum LED in combination with 16 h light duration feasible to be implemented in brassica cultivation under controlled environment.

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