Vol. 11, No. 2 (2022) : 314 - 324
DOI : http://dx.doi.org/10.23960/jtep-l.v11i2.314-324

JURNAL TEKNIK PERTANIAN LAMPUNG

ISSN 2302-559X (print) / 2549-0818 (online)
Journal homepage : https://jurnal.fp.unila.ac.id/index.php/JTP

Optimization of Fooder Sorghum (*Sorghum Bicolor* L. Moench) Growth in a Closed Hydroponic System Through Combination of Red and Blue LED Lighting

Radi[1]✉, Yuwan Nanda Adyatma[1], Makbul Hajad[1]

[1]Dept. Agricultural and Biosystem Engineering, Faculty of Agricultural Technology , Gadjah Mada University, Yogyakarta, INDONESIA

Article History :

Received : 14 February 2022
Received in revised form : 10 May 2022
Accepted : 30 May 2022

Keywords :
Closed hydroponic system,
Control systems,
Growth optimization,
Sorghum plant,
Red and blue LED light

✉Corresponding Author:
radi-tep@ugm.ac.id

ABSTRACT

Plant cultivation with a closed hydroponic system needs to be developed as a food production solution in the future. With this technology, plant growth parameters (including light parameters) can be adjusted according to needs so that plants can grow optimally. Red and blue light are needed for sorghum cultivation. This study aims to analyze the effect of the combination of red and blue LED lights on the growth of sorghum plants and determine the optimal ratio between the two light sources based on the plant growth rate in a closed hydroponic system. The plant growth parameters measured included plant height, stem diameter, number of leaves, leaf area, leaf color, wet weight, dry weight, water consumption, and morphology of sorghum plants. This research is conducted by constructing the nine combination of red and blue LED light with the control system placed inside each closed hydroponic box. The results confirmed that the use of red and blue LED light combinations has a significant effect on the growth rate of sorghum. The optimum combination of red and blue LED light is obtained from combination of R7:B1 with the conversion ratio of 9.53 kg fresh product per kg sorghum seed.

1. INTRODUCTION

Sorghum (*Sorghum bicolor* L. Moench) is a type of cereal plant belonged to the grass family (Sumarno *et al*., 2017). This plant is widely used by the community, including as food, animal feed, fuel and industrial raw materials (Aruna *et al*., 2018). As fodder for livestock, this plant can be harvested at a young age as forage. Forage sorghum is very favored by livestock, especially for plants that are still young (Koten *et al*., 2014).

Good quality forage is a basic need that is increasingly difficult to fulfill by farmers in Indonesia, partly due to limited land and the effects of climate change. The conversion of productive agricultural land into industrial and residential land is also an obstacle to the availability of animal feed (Sirappa, 2003). Several references state that the majority of cattle breeders in Indonesia do not have their own land to provide forage feed. Climate change also affects the quality and quantity of forage production (Rachmawati, 2019). As experienced by cattle farmers in Garut, whose livestock experienced a decrease in milk production by 20 percent due to the poor quality of fresh grass feed caused by bad weather (Ghani, 2019).

Sorghum is suitable to be developed as green fodder for livestock with a closed hydroponic system, a hydroponic system equipped with a continuous and recycled nutrients, which is commonly called a hydroponic fodder. Planting in this way has advantages such as being free of contaminants and pesticides, as well as being more efficient in water consumption compared to cultivation on solid media (Wahyono & Sadarman, 2020). Hydroponic feed cultivation is carried out using only water media and is carried out in a short life period of 7-14 days with a controlled environment (Wahyono *et al*., 2018).

Forage, which is harvested in the vegetative period after germination, can provide good nutritional feed to improve health and increase animal resistance (Wiskerchen, 2014). Fodder has a relatively high feed quality value. More than 90 percent of fodder is easily digested so it will make livestock gain weight faster and grow healthy (Cowling, 2017). Nutrients in fodder 4-6 times more than in mature plants (Xiao *et al*., 2012).

Reskynawati (2014) said that green leafy plants utilize sunlight for the photosynthesis process, so plants need an adequate supply of light. In general, sunlight has a central role in plant physiological processes such as photosynthesis, respiration, growth and development, closing and opening of stomata, plant germination, and plant metabolism, thereby determining the level of plant production (Salisbury & Ross, 1995). Light parameters that are important in this physiological process are intensity, spectrum quality, and length of irradiation. The photosynthesis process will be optimal if these three parameters are met (Taniputra, 1977).

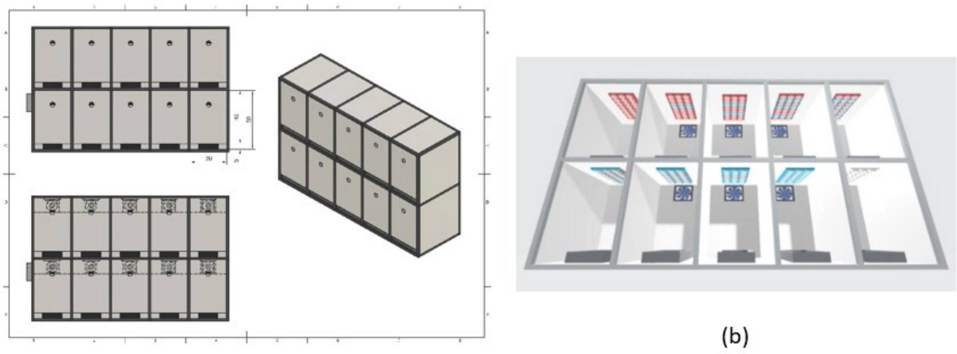
There are two main types of chlorophyll in plants, namely a-chlorophyll and b-chlorophyll. a-Chlorophyll effectively absorbs a spectrum of 429 nm (blue) and 659 nm (red), while b-chlorophyll has the ability to absorb a spectrum of 455 nm (blue) and 642 nm (red) (Berg *et al*., 2002). Because chlorophyll is an important component in the process of photosynthesis, its ability to absorb light will determine the rate of photosynthesis. Based on the characteristics of chlorophyll in plants, blue and red light are key in this photosynthesis process. Therefore, the provision of red and blue light can provide benefits for plant growth and development. Red light can increase leaf size, stem length, and can produce the largest heavy plants. With the addition of a little blue light, the plants will be more compact and generally have better quality, but the leaf size is slightly reduced and suppresses shoot growth (Wollaeger & Runkle, 2014). According to (Runkle, 2015), the color composition of a good LED light for plants is at least 75-90 percent red light and 10-20 percent blue light. However, the optimal ratio of red and blue light for sorghum plant growth has not been studied. This study aims to study the effect of the composition of red and blue light on the cultivation of sorghum as fodder in a closed hydroponic system. Specifically, the research aimed to (1) determine the effect of red and blue LED lights on height, stem diameter, number of leaves, leaf area, leaf color, wet weight, dry weight, water consumption, and morphology of hydroponic fodder sorghum plants; (2) determine the ratio of red and blue LED lights that can produce the best hydroponic fodder sorghum growth; and (3) knowing the effect of red and blue LED lights on the conversion of the best fresh weight of hydroponic fodder sorghum.

2. MATERIALS AND METHODS

2.1. Materials and Equipment

The materials used in this study were sorghum seeds of the Bioguma 3 Agritan variety, and mineral water. The equipment used for assembling the chamber is 36 red LED modules (620-625 nm, 100 mA, 120 Lm/LED, 12 VDC, 3 W), 36 blue LED modules (450-456 nm, 100 mA, 120 Lm/ LED, 12 VDC, 3 W), 8 white LED modules (10000K, 100 mA, 120 Lm/LED, 12 VDC, 3 W), 10 DC fans (12VDC, 0.15A, 8 cm diameter), power supply (power supply) as much as 2 pieces (12V 20A), cable (type NYZ, 2x0.75 Sqmm, 300V), PLN power source (AC, 220V), rack with 10 boxes (chamber) measuring 45 cm x 30 cm x 45 cm per chamber (Figure 1), impraboard (3mm thick), aluminum foil (14 micron thick) as reflectors and 10 hydroponic trays (24.5 cm x 9.5 cm x 3 cm) for planting.

The measuring instruments used are ruler/ruler, digital caliper, digital scale (MH-Series, capacity 200 g, accuracy 0.01 g), luxmeter (Smart Sensor AS803), 10 ml measuring cup, thermohygrometer (HTC-1), and camera (Google Pixel 2). Supporting tools for data analysis include oven (Sharp, Libre Series, 18 L, 800 W, 220-240 V), SPSS 16 program, ImageJ 1.53e program and Excel 2016 program.



(a) (b)

Figure 1. Chamber design: (a) dimensions for 10 chambers, (b) inside view of the chamber

2.2. Research procedure

The research begins with the preparation of tools and materials, followed by assembling the chamber and LED lights and installing fans. The chamber is made by making a rack frame which is then divided into 10 boxes (chambers) and coated with aluminum foil (9 chambers for treatment and 1 chamber as control). Each chamber is equipped with lighting from a combination of red-blue LED lights with a ratio according to the treatment in the study. Each chamber is equipped with 8 LED lights in an arrangement as presented in Table 1. The sequence of lights (1 to 8) shows the order of installation of 8 LED lights mounted above the chamber as a lighting source for each treatment (8:0 to C).

The series of lights are installed at the top of the chamber facing the plant at a distance of 40 cm from the surface of the growing media. The distance of 40 cm is determined based on the height of the white light with a value of 10000 Lux (Robinson, 2020). To maintain air circulation, each chamber is given a fan. The electrical circuit of the Red-Blue LED lights is presented in Figure 2. After the hardware is assembled, the activity is continued with a functional lighting test (Figure 3), measuring the environmental conditions of the chamber including light intensity, temperature and humidity.

Table 1. Arrangement of Ratios of Red-Blue LEDs

Lamp Order	Light Ratio: Red : Blue 8:0	7:1	6:2	5:3	4:4	3:5	2:6	1:7	0:8	C
1										
2										
3										
4										
5										
6										
7										
8										

Remark:
LED Red
LED Blue
LED White

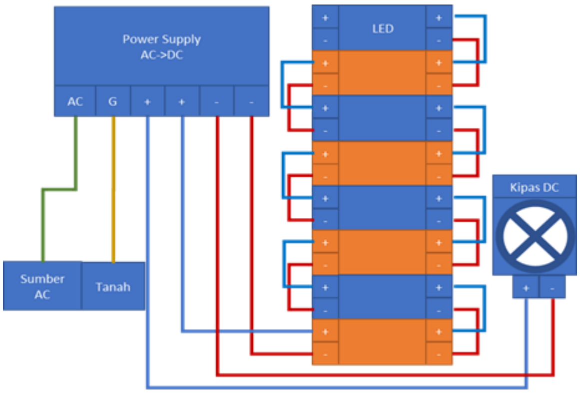


Figure 2. The electrical circuit of the LED lamp

Figure 3. Functional test chamber with LED light on

After the functional test was completed, the activity continued with the preparation of sorghum seeds through 36 hours of immersion. After soaking, the seeds are planted in a hydroponic tray. Maintenance is carried out every day by adding hydroponic water to the base of the plant stem. Radiation is carried out for 18 hours per day (Mardianita, 2017). Observations of growth parameters were carried out every day from planting to harvesting. Plants were harvested on the 14^{th} day, followed by measuring stem diameter, wet weight, dry weight, measuring leaf area, leaf color, and amount of water usage, plant morphology and calculating the conversion of fresh fodder yields. Observation of leaf area was done by taking the second leaf of each plant. Observation of leaf color was done by taking several leaf samples from each treatment. Each chamber is planted with 40 sorghum seeds arranged in two rows of plants.

2.3. Data Analysis Method

Analysis of observational data is presented in the form of graphs (curves and histograms), data tables, and photos of documentation of the results. Light intensity data was taken at the beginning of the study, temperature, humidity and plant height parameters were observed every day until harvesting day (14th day), stem diameter data, number and leaf area, wet weight, dry weight, leaf color and amount of water usage were observed at harvest time.

3. RESULTS AND DISCUSSION

3.1. Chamber Light Intensity, Temperature and Humidity

Measurements of light intensity, temperature and humidity were carried out at the beginning of the study. During cultivation, these parameters are kept constant. The results of the measurement of light intensity can be seen in Figure 4. From the graph it can be seen that the higher the ratio of blue LEDs, the higher the light intensity. The highest light intensity was at C (control with white light) and R0:B8 (the number of red LEDs (R, red) was 0 and blue LEDs (B, blue) were 8) and the lowest was at R8:B0 for treating the ratio of red-blue LEDs. Meanwhile, data on the average temperature and humidity in the chamber are presented in Table 2. Temperature tends to decrease in light with a higher ratio of blue, while humidity tends to increase in light with a higher ratio of blue. The average temperature during the study was 29.73ºC and the RH was 71.60%. The optimum temperature limit for sorghum growth is between 21-35°C (Aqil & Bunyamin, 2013) and humidity below 75% (Ishak *et al*., 2012).

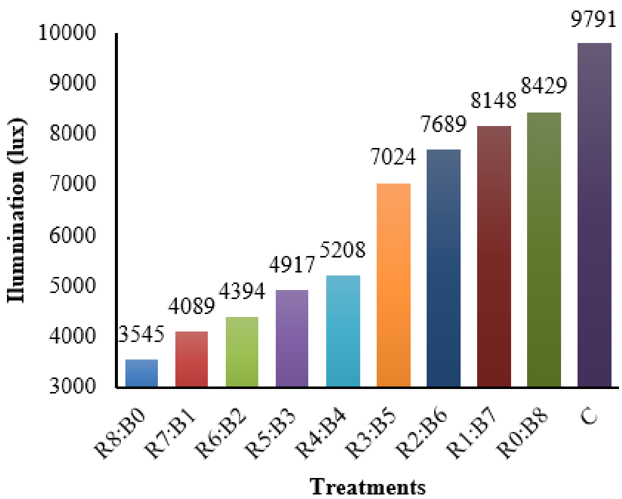


Figure 4. Light Intensity

Table 2. Averages of chamber temperature and humidity

	R8:B0	R7:B1	R6:B2	R5:B3	R4:B4	R3:B5	R2:B6	R1:B7	R0:B8	C
Temperature (°C)	29,96	29,82	29,89	29,87	29,87	29,71	29,57	29,57	29,45	29,55
RH%	70,80	71,40	70,67	70,60	70,67	71,67	71,93	72,20	73,40	72,67

3.2. Plant Growth, Leaf Color, and Water Consumption

The increase in plant height during 14 days of planting can be seen in Figure 5 while the rate of increase in plant height is presented in Figure 6. Based on Figure 6, the rate of increase in plant height (growth rate) at the beginning of germination until day 5 looks high, then the growth rate looks constant. The growth rate in red dominant light was higher than in blue dominant light. This is because plant photoreceptors are more sensitive to red light where exposure to this light on photoreceptors will be used to activate plant growth and development genes more quickly than exposure to other color light (Anonymous, 2020). In addition, flavonoids and carotenoids in plants also absorb blue light so that the absorption of chlorophyll against blue light becomes less efficient (Liu & van Iersel, 2021).

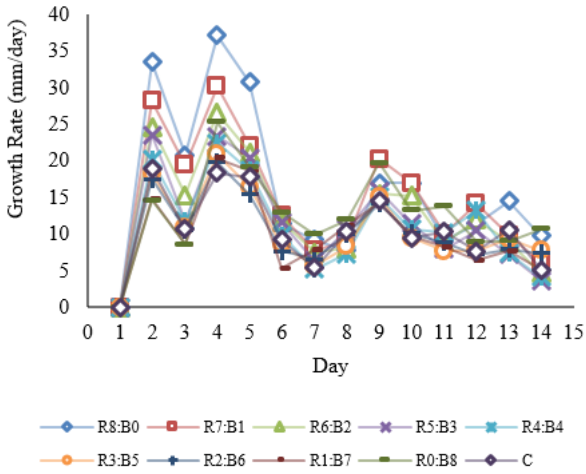


Figure 5. Increase in plant height

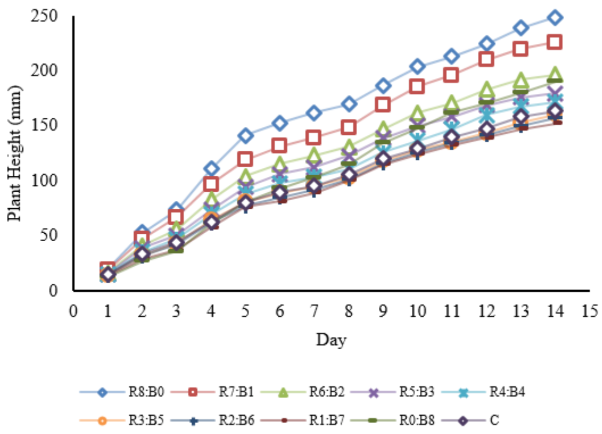


Figure 6. Growth Rate in term of plant height

In addition to periodic measurements, as the final indicator of plant growth, several parameters of the final *product* were measured including plant height, stem diameter, number of leaves, leaf area, leaf color, wet weight and dry weight. The results of the measurement of these parameters are presented in Table 3. Based on these data, it can be seen that the highest plants were obtained at the ratio R8:B0 and R7:B1 and the lowest at the ratio R1:B7. The average plant height tends to decrease with the increasing ratio of blue color. Plant height in the R0:B8 ratio was slightly higher than the ratio with the red-blue combination, but still lower than the R6:B2 ratio treatment; R7:B1; and R8:B0.

Table 3. Data of Final Plant Product

Parameter	R8:B0	R7:B1	R6:B2	R5:B3	R4:B4	R3:B5	R2:B6	R1:B7	R0:B8	C
Plant height, mm	248,7	226,0	196,5	179,5	171,5	160,3	157,3	151,9	190,4	163,3
Stem diameter, mm	0,81	0,86	0,87	0,87	0,98	0,99	1,06	1,06	0,80	0,90
Number of leaves	3,20	3,28	3,28	3,30	3,35	3,38	3,40	3,43	3,33	3,40
Luas daun, mm	2,80	2,63	2,37	2,18	1,93	1,57	1,57	1,45	1,27	1,21
Color (L)	55,3	54,8	54,6	53,8	53,3	52,2	51,8	51,6	55,8	53,1
Color (a*)	-15,6	-15,9	-16,1	-15,4	-16,4	-15,3	-15,7	-16,7	-14,9	-15,6
Color (b*)	43,9	43,9	44,8	43,3	41,2	40,6	40,5	39,2	45,1	45,1
Total water consumption, mL	845,8	832,0	819,4	792,0	761,4	743,4	739,0	737,0	750,0	737,6
Total wet weight, g	16,52	16,29	14,83	14,32	13,18	12,42	12,37	11,13	10,62	10,18
Root wet weight, g	7,03	9,01	8,07	7,69	6,87	6,88	6,97	6,18	5,59	5,27
Stem wet weight, g	9,49	7,28	6,76	6,63	6,31	5,54	5,40	4,95	5,03	4,91
Total dry weight, g	1,49	1,60	1,41	1,36	1,26	1,24	1,24	1,17	1,13	1,20
Root dry weight, g	0,44	0,61	0,51	0,48	0,43	0,46	0,49	0,46	0,42	0,44
Stem dry weight, g	1,05	0,99	0,90	0,88	0,83	0,78	0,75	0,71	0,71	0,76

The average stem diameter tends to increase with increasing blue color ratio. The highest stem diameter was obtained at the ratio R1:B7 and R2:B6 and the lowest at the ratio R0:B8. The leaf area parameter tends to increase with the number of red light ratios. The highest leaf area at the ratio of R8:B0 and R7:B1. The results of leaf color measurements (*La*b**) showed values that tended to be the same between treatments.

The highest total water use occurred at the ratio R8:B0 followed by R7:B1 and the lowest at the ratio R1:B7. The high temperature in the red light treatment causes high water absorption. This high temperature is because red light is absorbed more strongly by photosynthetic pigments. This strong absorption causes dissipation of excess energy heat in the chloroplasts on the surface of the leaf, while the chloroplasts deeper in the leaf receive less energy. So that the light used is not completely absorbed by chlorophyll and tends to be lost as heat (Liu & van Iersel, 2021).

The highest total wet weight was produced at a ratio of R8:B0, which was 18.52 gr, followed by an R7:B1 ratio of 16.29 gr and the lowest was at an R0:B8 ratio of 10.62 gr. Although the wet weight at the R8:B0 ratio was high, the plants looked less healthy, especially on underdeveloped and slightly brownish roots. Meanwhile, in the R7:B1 ratio, although the wet weight was slightly lower than the R8:B0 ratio, the plants grew the healthiest, and the roots developed well. According to (Runkle, 2017) proper blue light is needed so that growth is not inhibited and does not cause etiolation. Inhibited growth can reduce plant weight (Lobiuc *et al.*, 2017) and etiolation can reduce plant dry weight (FuseSchool, 2017).

The highest total dry weight was obtained at the ratio R7:B1, which was 1.6 g and the lowest total dry weight was obtained at the ratio R0:B8 of 1.13 g. The high dry weight in the R7:B1 treatment is thought to be the most effective combination of red-blue light ratio at the R1:B7 ratio compared to other treatments. This is in accordance with the opinion (Ouzounis *et al.*, 2016) that the combination of red and blue LED lighting can increase the total dry matter compared to red LEDs alone. Red light increases leaf size and stem length, which results in the plants having the greatest weight (Wollaeger & Runkle, 2014).

3.5. Plant Morphology

Plant morphology observations were carried out to determine the growth of plant roots and stems. Observations were made on the last day of planting (after harvesting) by scanning using a camera. Morphological data of sorghum plants from the observed treatments are presented in Figure 7. Based on observations, sorghum plants for all treatments appeared to grow normally. When the ratio of blue light increased, the stem diameter and number of leaves increased, but on the observation of leaf area, wet weight, dry weight, moisture content and conversion value of fodder results decreased and vice versa for red light. This shows that variations in the combination of red and blue light can affect plant growth.

R8:B0 R7:B1 R6:B2 R5:B3 R4:B4 R3:B5 R2:B6 R1:B7 R0:B8 C

Figure 7. Morphology of sorghum plants consisting of stems and leaves (top) and plant roots (bottom) for each treatment

Based on morphological data, the ratio of R7:B1 resulted in the best plant growth compared to other treatments. Plants grow healthy and strong with healthy roots. It is suspected that the combination of red-blue light at a ratio of R7:B1 can synergize with each other to support the growth process properly. According to Lobiuc *et al*. (2017), red light will maximize light absorption by chlorophyll, while blue light will induce stomata opening, thus enabling better CO_2 fixation and inhibition of growth hormone. The right ratio of red-blue light will result in high weight, even growth between stems and roots, and increased immune and antioxidant activity (Andrea, 2021; Ouzounis *et al*., 2016; Roden & Ingle, 2009; Wollaeger & Runkle, 2014; Xu *et al*., 2019). Root growth in the R7:B1 ratio treatment looked the best compared to other treatments, where the roots were the whitest, grew long and developed well. This is in accordance with the opinion (Xu *et al*., 2019) which says that the quality of light affects the level of environmental stress in plants and antioxidants (APX) in the antioxidant enzyme system make plants more tolerant of environmental stress, encourage photosynthesis of leaves and distribution of photosynthesis to roots. so the roots grow. The combination of red-blue light, with a higher ratio of red light will increase the activity of higher antioxidant (APX) and lower oxidizing agent (PPO) which is often associated with browning (Xu *et al*., 2019).

4. CONCLUSIONS AND RECOMENDATION

Research on the effect of the combination of red-blue LED lights on the cultivation of sorghum for animal feed in a closed hydroponic system has been carried out. Based on this research, the use of a combination of red-blue LEDs has an effect on the growth of sorghum plants. The combination of red-blue LED lights with a red-blue ratio of R7:B1 can produce the best hydroponic fodder sorghum growth compared to other treatments. The use of the R7:B1 ratio can provide optimal light requirements for the growth of hydroponic fodder sorghum which is indicated by the results of measurements of plant height, leaf area, wet weight, high dry weight, and the appearance of the most healthy plant morphology which shows the role of antioxidant and immune functions in sorghum plant growth. At this ratio, the conversion of fresh fodder produced is 9.53 kg/kg of sorghum seed.

ACKNOWLEDGMENT

This research received facility support from the Program Kompetisi Kampus Merdeka (PKKM) - Study Program of Agricultural Engineering, Department of Agricultural and Biosystem Engineering, Faculty of Agricultural Technology, Universitas Gadjah Mada, year of 2021.

REFERENCES

Adyatma, Y.N. (2022). Optimasi kombinasi lampu led merah dan biru terhadap pertumbuhan tanaman sorgum (*Sorghum bicolor* L. Moench) pada sistem hidroponik. [*Undergraduate Thesis*]. Faculty of Agricultural Technology, Universitas Gadjah Mada

Andrea. (2021). What color plant roots should be? Your indoor herbs and garden. https://www.yourindoorherbs.com/what-color-roots-should-be/

Anonim. (2020). *Photoreceptor Proteins*. LibreTexts. https://chem.libretexts.org/@go/page/479

Aqil, M., & Bunyamin, Z. (2013). Pengelolaan air tanaman sorgum. In *Sorgum: Inovasi Teknologi dan Pengembangan*, 1, 118–204.

Aruna, C., Visarada, K.B. R. S., Bhat, B.V., & Tonapi, V.A. (2018). *Breeding Sorghum for Diverse End Uses*. Wood Head Publishing, Cambridge, MA, USA.

Berg, J., Tymoczko, J., & Stryer, L. (2002). *Biochemistry*, 5th edition. W. H. Freeman Publishing, New York.

Cowling, M. (2017). Best Hydroponic Fodder System For Sustainable Farming—YouTube. Fodder Group Inc. https://www.youtube.com/watch?v=b2XYLEliMhQ

FuseSchool. (2017). *Plant Growth: Auxins and Gibberellins*.

Ghani, H. (2019). Produksi susu sapi di garut menurun akibat cuaca buruk. https://news.detik.com/berita-jawa-barat/d-4388545/produksi-susu-sapi-di-garut-menurun-akibat-cuaca-buruk

Ishak, M., Sudirja, R., & Ismail, A. (2012). Zonasi kesesuaian lahan untuk pengembangan tanaman sorgum manis (*Sorgum bicolor* (L) Moench) di Kabupaten Sumedang berdasar analisis geologi, penggunaan lahan, iklim, dan topografi. *Jurnal Ilmu-Ilmu Hayati dan Fisik*, ***14***(3), 173-183.

Koten, B.B., Soetrisno, R.D., Ngadiyono, N., & Soewignyo, B. (2014). Perubahan nilai nutrien tanaman sorgum (*Sorghum bicolor* (L.) Moench) varietas lokal rote sebagai hijauan pakan ruminansia. *Pastura*, ***3***(2), 55–60. https://doi.org/10.24843/Pastura.2014.v03.i02.p01

Liu, J., & van Iersel, M.W. (2021). Photosynthetic physiology of blue, green, and red light: light intensity effects and underlying mechanisms. *Frontiers in Plant Science*, March. https://doi.org/10.3389/fpls.2021.619987

Lobiuc, A., Vasilache, V., Pintilie, O., Stoleru, T., Burducea, M., Oroian, M., & Zamfirache, M.M. (2017). Blue and red LED illumination improves growth and bioactive compounds contents in acyanic and cyanic *Ocimum basilicum* L. microgreens. *Molecules*, ***22***(12), 2111. https://doi.org/10.3390/molecules22122111

Mardianita, S. A. (2017). Pengaruh lama penyinaran lampu led terhadap pertumbuhan dan hasil produksi selada (*Lactuca sativa*, L.) hidroponik. [*Undergraduate Thesis*]. Teknik Pertanian, Fakultas Teknologi Pertanian, Universitas Andalas, Padang.

Ouzounis, T., Heuvelink, E., Ji, Y., Schouten, H.J., Visser, R.G.F., & Marcelis, L.F.M. (2016). Blue and red LED lighting effects on plant biomass, stomatal conductance, and metabolite content in nine tomato genotypes. *Acta Horticulturae*, ***1134***, 251–258. https://doi.org/10.17660/ActaHortic.2016.1134.34

Rachmawati. (2019). Terkendala pakan ternak, produksi susu lokal hanya penuhi 20% kebutuhan. *Pikiran-Rakyat*. https://www.pikiran-rakyat.com/ekonomi/pr-01320746/index.html

Reskynawati, K. (2014). Pertumbuhan dan produksi tanaman kacang hijau (*Vigna radiata* L.) pada berbagai tingkat naungan. [*Undergraduate Thesis*]. Program Studi Agroteknologi, Jurusan Budidaya Pertanian, Fakultas Pertanian, Universitas Hasanuddin, Makassar.

Robinson, P. (2020). How much light do my indoor plants need? - PlantMaid. https://www.plantmaid.com/how-much-light-do-my-indoor-plants-need/

Roden, L.C., & Ingle, R.A. (2009). Lights, rhythms, infection: The role of light and the circadian clock in determining the outcome of plant-pathogen interactions. *Plant Cell*, ***21***(9), 2546–2552). https://doi.org/10.1105/tpc.109.069922

Runkle, E. (2015). Light wavebands & their effects on plants. *GPNMAG*, March, 42.

Runkle, E. (2017). Effects of blue light on plants. *GPNMAG*, February, 38.

Salisbury, F.B., & Ross, C.W. (1995). *Fisiologi Tumbuhan* (Jilid 2). Translated by Diah R. Lukman and Sumaryono. Institut Teknologi Bandung.

Sirappa, M.P. (2003). Prospek pengembangan sorgum di indonesia sebagai komoditas alternatif untuk pangan, pakan, dan industri. *Jurnal Litbang Pertanian*, ***22***(4), 133–140.

Sumarno, Syam, M., Damardjati, D.S., & Hermanto. (2017). Sorgum: Inovasi Teknologi dan Pengembangan. IAARD Press, Badan Penelitian dan Pengembangan Pertanian, Jakarta.

Subronto, S., Taniputra, B., Hastjarjo, H. (1977). Pengaruh intensitas cahaya matahari terhadap pertumbuhan bibit kelapa sawit. *Bull. Balai Penelitian Perkebunan*, ***8*** (4), 125-141.

Wahyono, T., & Sadarman, S. (2020). Hydroponic fodder: Alternatif pakan bernutrisi di masa pandemi. *Prosiding Seminar Teknologi Agribisnis Peternakan* (STAP) Fakultas Peternakan, Universitas Jenderal Soedirman, 558–566.

Wahyono, T., Hardani, S.N.W., & Sugoro, I. (2018). Low irradiation dose for sorghum seed sterilization: Hydroponic fodder system and in vitro study. *Buletin Peternakan*, ***42***(3), 215-221. https://doi.org/10.21059/buletinpeternak.v42i3.30888

Wiskerchen, J. (2014). Growing sprouted fodder for livestock by Jason Wiskerchen. https://thatoldschoolgirlagain.wordpress.com/2014/01/21/growing-sprouted-fodder-for-livestock-by-jason-wiskerchen/

Wollaeger, H.M., & Runkle, E.S. (2014). Growing seedlings under LEDs: Part two. *Greenhouse Grower*, February, 40–41.

Xiao, Z., Lester, G.E., Luo, Y., & Wang, Q. (2012). Assessment of vitamin and carotenoid concentrations of emerging food products: Edible microgreens. *Journal of Agricultural and Food Chemistry*, ***60***(31), 7644–7651. https://doi.org/10.1021/jf300459b

Xu, Y., Liang, Y., & Yang, M. (2019). Effects of composite LED light on root growth and antioxidant capacity of *Cunninghamia lanceolata* tissue culture seedlings. *Scientific Reports*, ***9*****,** 9766. https://doi.org/10.1038/s41598-019-46139-2