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Growth and yield pattern of microgreen under different types of artificial lighting

Abstract. Microgreen is a popular food product that is interesting to study and can be produced in the building with the support of artificial light, especially in terms of smart lights. This study aims to analyze the growth and yield response of red amaranth, red radish, and coriander microgreens under different types of light color treatment from smart lights. The study was conducted in August 2022 at the microgreen culture room, Department of Agronomy, Universitas Padjadjaran, Indonesia, using a completely randomized design with two factors, namely three levels of plant species and five levels of smart light color. The results showed differences in seed viability, first-day count, and the day the cotyledons were open among three microgreen species. Seed growth into microgreens had the same pattern, namely linear and positive, even in the light absence condition as the evidence of etiolation occurrence leading to the production of thin and yellow pale color of microgreens. The difference in light color is specific to each type of plant. Red radishes thrived in all colors, although red light tended to do better. On the other hand, red amaranth was inhibited in red light and coriander in white light. Blue light is strongly recommended for increasing red amaranth and coriander microgreens yields.

Keywords: Red amaranth · Red radish · Coriander · Smart lamp · Microgreen

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Introduction

Microgreen is a food ingredient that is produced simply as a form of continued development of sprouts (Verlinden, 2020) with a crispy texture and attractive colors and is easily found in modern food, such as salads and sandwiches (Renna et al., 2017; Turner et al., 2020). It is a new popular culinary trend in recent years, especially among urban communities (Stoleru et al., 2016; Riggio et al., 2019a), that is used as a garnish to increase the aesthetic value of food appearance.

In addition to aesthetic aspects, microgreen also offers health benefits since it contains vitamins, minerals, carotene, and antioxidant compounds (Xiao et al., 2012; 2015; 2016; 2019). Some plants are new idols of microgreen, e.g., red radish, red amaranth, and coriander. Red radish microgreens are rich in anthocyanins (Zhang et al., 2019). Red amaranth contains higher carotenoid lutein/zeaxanthin (Xiao et al., 2012). Coriander microgreen contains more phenol and terpene than its vegetable form (Oruna-Concha, 2017). It is strongly stated that microgreen is functional food to maintain good health (Choe et al., 2018).

The attractiveness of microgreens in terms of aesthetics and health increases people's interest in producing microgreens. The production of this microgreen can be carried out both outdoors and indoors. The consequence of producing microgreens indoors is the need for artificial irradiation support to replace the sunlight. The development of technology has now allowed interaction between the field of artificial intelligence and agriculture, such as smart artificial lamps. The advantage of using smart lamps is the ease of setting the on/off and color types automatically anytime, anywhere.

The arrangement of these lamps is interesting to study because the light is one of the abiotic factors determining plant growth and development (Gupta et al., 2018). Lamp selection is more advisable to use light-emitting diodes than fluorescent tubes with energy-saving considerations (Shukla et al., 2017). Previous research has reviewed the influence of artificial LED lamp colors on microgreens' growth, yield, and phytochemical content (Putri et al., 2022). But more specific research on new microgreen idols, such as red radish, red amaranth, and coriander, is still limited. This study aims to analyze the growth response and microgreen results of red radish, red amaranth, and coriander in response to different light colors of smart lamps.

Materials and Methods

This experiment was conducted at the microgreen culture room, Department of Agronomy, Universitas Padjadjaran, in August 2022. The microgreen planting material used is the seeds of the red amaranth (*Amaranthus cruentus* L.), red radish (*Raphanus sativus* L.), and coriander (*Coriandrum sativum* L.). Seeds were obtained from the online market. The germination medium of vermiculite for about 8.5 g is placed in a plastic bowl planting container and arranged according to the experimental design.

This study used an experimental design in the form of a Factorial Randomized Completely Blok Design consisting of two factors: the type of microgreen and the color of the lamp. The first factor, namely the type of microgreen, consists of three levels, i.e., red amaranth, red radish, and coriander. In contrast, the second factor, namely the lamp's color, consists of five levels, i.e., white, red, blue, purple (a combination of red and blue), and dark conditions.

This study was composed of 15 combinations of treatments replicated 18 times to accommodate three tests in each destructive observation, and in total, there were six destructive observations.

This study used a multistage planting rack according to the illustration in Figure 1A. At each level, smart lights are installed on the roof at a distance of 30 cm from the surface base of each shelf. Smart lamps can be adjusted the color type on smartphones with the help of wi-fi. Using smart lights also makes it easier to set the length of the day/photoperiodic, namely 10 hours of day and 14 hours of dark, by using the scheduling feature so that the smart lights will turn on and out automatically according to the predetermined schedule.

On each shelf, the microgreen planting container is arranged in a circle according to the illustration in Figure 1B. Each circle has three types of microgreens with the same number of replications. This is intended to avoid variations in the irradiation intensity between the innermost circle close to the light source and the outermost circle further away from the light source. For dark treatment, planting containers are arranged and located in plastic boxes on the top shelf. The color of the lamp from the second layer up to the bottom in successive ways are as follows: red, purple, blue, and white (Figure 1B). The walls on each shelf are covered with black cloth to minimize the light bias from other treatments.

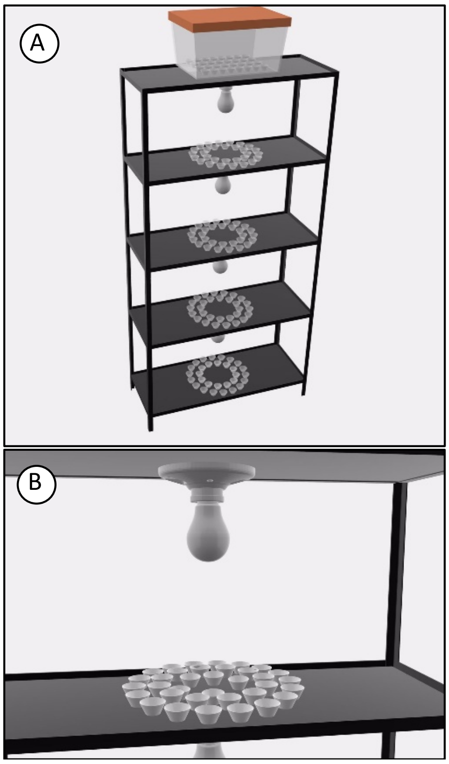

Figure 1. A) illustration of multi-storey racks and placement of smart lights, B) illustration of microgreen containers at each shelf level.

Microgreen planting is carried out by soaking the seeds in warm water for 8 hours before sowing. Post-soaking seeds are ready for sowing, with about 20 seeds in each planting container. Watering is carried out every two days with the sprayer. The volume of watering per planting container is 10 mL.

The observation was carried out on the variable of growth and yield. Growth improvement were represented by hypocotyl length and microgreen fresh weight that were carried out daily and destructively from the 2nd to the 7th day after germination. The hypocotyl length was measured using a mini ruler from the base of the growing medium to the base of the opening leaves. The fresh weight of microgreen was weighed using an analytical balance with an accuracy scale of 0.001 g. The increase in the hypocotyl length and the microgreen's fresh weight were presented in the form of line charts. Data on the microgreen hypocotyl length and fresh weight on the 7th day were tested by analysis of variance and Duncan’s test on SPSS software. Other variables observed were seed viability, first-day count, first-day of leaves open, hypocotyl color, leaves color and shape; however, it was not followed by statistical analysis, only describe qualitatively.

Results and Discussion

Microgreen Growth. There were statistically differences of seed viability among tested genotypes, with the highest value in the type of red radish at 100%, red amaranth at 90%, and coriander at 75% (Table 1). Seed viability is defined as the seed ability to germinate normally under optimal conditions. The difference in seed viability could be caused by genotype factors and the actual condition of seed quality. Low viability is one of the indicators for seed quality deterioration. Improper seed storage is one of the factors causing the seed quality deterioration (Copeland & McDonald's, 2001).

Table 1. Seed viability, the first day of germination, and the first day of fully open leaves of microgreens.

Changer of Observations	Plant Genotype		
	Red Amaranth	Red Radish	Coriander
Seed viability	90%	100%	75%
First-day count	3 DAS	3 DAS	6 DAS
First-day of leaves open	5 DAG	4 DAG	7 DAG

Notes: The seed viability is obtained from the number of normal germinated seeds divided by the number of seed sowed in the container and expressed in percentage. DAS = day after sowing; DAG = days after germination

The genotype factor is also thought to be the cause of the difference in first-day count and first-day of leaves open. Red radish and red amaranth have similar first-day count, i.e., 3 days after sowing (DAS), while coriander takes a longer time to germinate, which is 6 DAS (Table

1). The next growth process is the lengthening of the hypocotyl and the opening of the leaves (Figure 2).

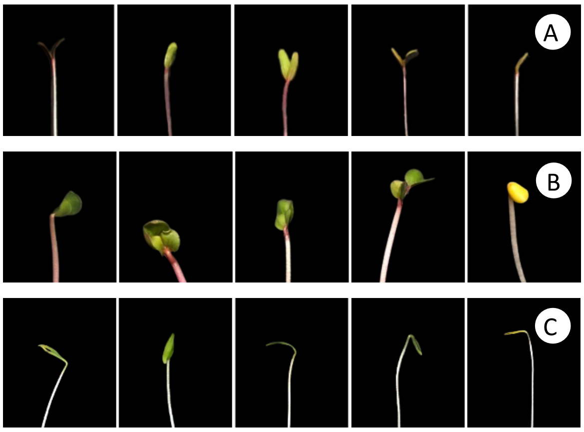

Figure 2. The color of hypocotyl and leaves of three microgreen species (A - red amaranth, B - red radish, C - coriander) at 7 DAG under different colors of artificial light, i.e. white, blue, purple, red, and dark (from left to right)

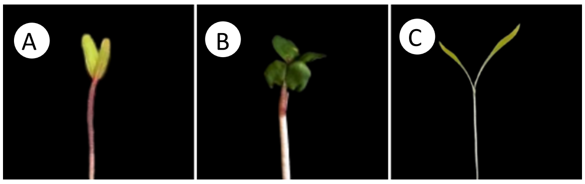

Figure 3. The leaf shape of three microgreen species, i.e., A) red amaranth, B) red radish, C) coriander.

The hypocotyl is the central part of microgreen that looks like a main stem. Hypocotyl is generally cylindrical, with colors varying depending on genotype and environmental factors. Red amaranth and red radish are reddish hypocotyls, while coriander is white. Ecological differences, in this case, artificial lighting treatment causes color differences, i.e., the dark caused pale yellow leaves, while lamp-treated microgreen displayed green color on red radish or light green in red amaranth and coriander (Figure 2).

The absence of light in dark treatment inhibits chlorophyll synthesis since chlorophyll becomes a green coloring agent on the leaves (Taiz & Zeiger, 2009). The longer a plant is exposed to the dark, the more etiolation observed, followed by a lower pigment content (Niroula et al., 2021).

Aside from hypocotyl, the leaf is also main counterpart of microgreen that is located at the tip of the hypocotyl growing point. The shape of the leaves is strongly influenced by genotype factors. The color of red amaranth, red radish, and coriander leaves is successively light green, dark green, and light green, respectively. The shape of these leaves is quite varied, namely oblong for red amaranth, obcordate for red radish, and linear for coriander (Figure 3). Red radish is determined as the fastest microgreen to reach fully open leaf condition, and then followed by red amaranth, and the slowest one is coriander (Table 1).

The results showed that there were linear and positive growth patterns of the three genotypes of microgreens under different artificial light treatments. It is proved by the increase in hypocotyl length and fresh weight of microgreens on the 7th day compared to the previous days (Figures 4 and 5).

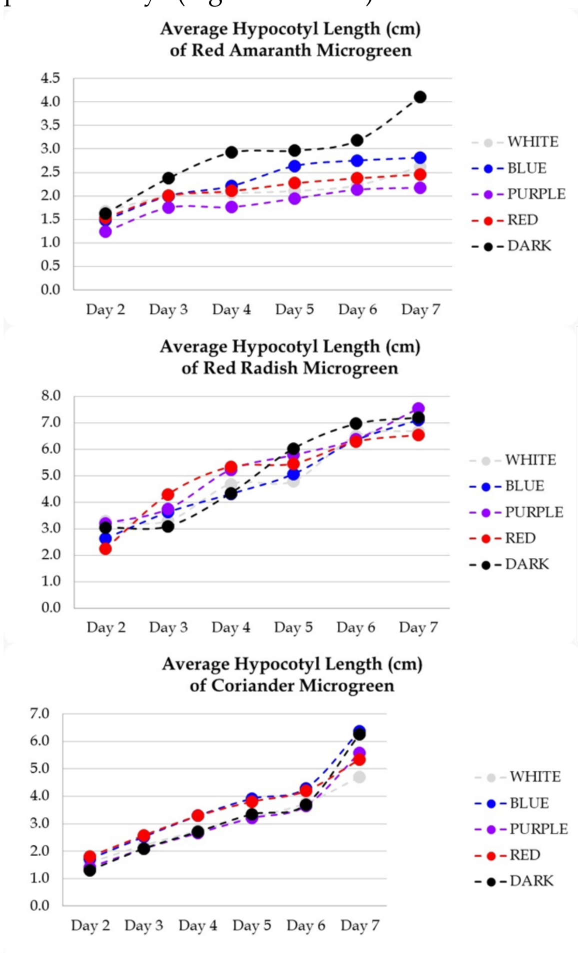

Figure 4. Daily (from day 2 to day 7) hypocotyl length (cm) of three microgreen types (red amaranth (top), red radish (middle), coriander (bottom)) under different light colors of artificial lamp.

The average of hypocotyl length gain in red amaranth microgreens illuminated by white light, blue light, purple light, red light and dark condition are as follows 0.37; 0.40; 0.31; 0.35; and

0.59 cm per day, respectively (Figure 4 above). In the case of fresh weights, the average of this microgreen white light, blue light, purple light, red light and dark condition are as follows 1.2; 1.2; 1.0; 1.0; and 1.2 mg per day, respectively (Figure 5 above). In the dark treatment, a very rapid increase in the length of the hypocotyl on day 7, was not followed by an increase in its hypocotyl weight. This makes the red amaranth microgreen appearance in the dark is thinner due to intense etiolation.

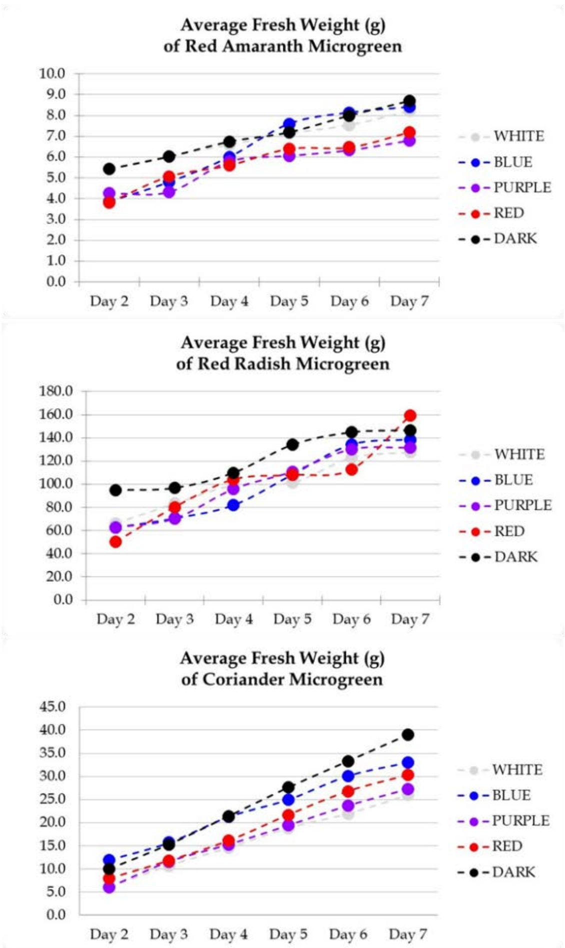

Figure 5. Daily (from day 2 to day 7) microgreen fresh weight (mg) of red amaranth (top), red radish (middle), coriander (bottom) under different light colors of artificial lamp.

In red radish, the mean of increase in hypocotyl length are 0.96; 1.01; 1.08; 0.93; and 1.03 cm per day, on white light, blue light, purple light, red light, and dark treatments, respectively (Figure 4 middle). This type of microgreen also experienced an increase in fresh weight by 18, 20, 19, 23, and 21 mg per day under white light, blue light, purple light, red light, and dark condition (Figure 5 middle).

The coriander microgreen response also showed an increase in hypocotyl length by 0.67; 0.9 1; 0.80; 0.76; and 0.89 cm per day under white light, blue light, purple light, red light and dark treatment, respectively (Figure 4 below). In parallel with the increase in the hypocotyl length, there was also an increase in microgreen fresh weight by 3.7; 4.7; 3.9; 4.3; and 5.6 mg per day due to white light, blue light, purple light, red light, and dark treatment (Figure 5 below).

Microgreen Yield Component. The microgreen yield component can be represented by microgreen fresh weight and hypocotyl length at 7 DAG. This early harvesting activity produces microgreen immature products with colors, sizes, and textures that are preferred compared to late harvesting at 14 DAG.

Table 2. Fresh weight of three types of microgreens at 7 days after germination (DAG) under different light colors of artificial lamp.

Treatment	Microgreen Weights (mg)
- Red Amaranth (*Amaranthus cruentus* L.) -	
White	8.2 b
Blue	8.4 b
Purple	6.8 a
Red	7.2 a
No lights	8.7 b
- Red Radish (*Raphanus sativus* L.) -	
White	127.8 a
Blue	138.5 a
Purple	131.7 a
Red	159.3 a
No lights	146.7 a
- Coriander (*Coriandrum sativum* L.) -	
White	26 a
Blue	33 ab
Purple	27.3 a
Red	30.3 ab
No lights	39 b

Note: The mean followed by the letter in the same column showed no significant difference based on Duncan's test at the level of 5 %.

There is a difference in microgreen fresh weights between genotypes with the highest value on red radish, while the smallest one in red amaranth. Light color treatment resulted in significant variations of fresh weight of red amaranth and coriander at 7 DAG. However, this is not significantly observed in red radish, although there is a tendency of superior result under red light irradiation (Table 2 and Table 3).

Dark-treated red amaranth has the highest fresh weight and hypocotyl length, as a result of a severe etiolation compared to light-treated microgreen. That results is also similar to previous study by Zelenkov et al., (2019). In red amaranth, the irradiation of red and purple actually produces a short hypocotyl and light microgreen. However, our finding was in contrary to previous report on tomatoes (Kalaitzoglou et al., 2019) and some species of the Brassicaceae family (Signore et al., 2020).

Table 3. Hypocotyl length of three types of microgreens at 7 days after germination (DAG) under different light colors of artificial lamp.

Treatment	Length of hypocotyl (cm)
- Red Amaranth (*Amaranthus cruentus* L.) -	
White	2.62 b
Blue	2.8 b
Purple	2.18 a
Red	2.46 ab
No lights	4.11 c
- Red Radish (*Raphanus sativus* L.) -	
White	6.69 a
Blue	7.10 a
Purple	7.53 a
Red	6.53 a
No lights	7.21 a
- Coriander (*Coriandrum sativum* L.) -	
White	4.71 a
Blue	6.38 b
Purple	5.59 ab
Red	5.35 ab
No lights	6.26 b

Note: The mean followed by the letter in the same column showed no significant difference based on Duncan's test at the level of 5 %.

For the production of red amaranth microgreen, the treatment of white or blue lamps is recommended since they can produce the best microgreens with a good fresh weight and full color (reddish) hypocotyl, as a sign of the carotenoids-rich, in contrast to pale white color under no light treatment.

In the case of coriander, the provision of white light actually produces the lowest yield, while blue light produces the best fresh weight and length of the microgreen. Similar result was also reported by Signore et al., (2020) who observed the superiority of blue light over white light. Previous study by Park et al., (2010) proved the influence of blue light in the induction of plant biomass production. The increase in growth response that leads to an increase in yield is thought to be main positive influence of blue light, especially related to the amount of chlorophyll, as reported by Ouzounis et al., (2016). The results of this study also justify that there is an opportunity to optimize microgreen yields by knowing the specifications of the desired color light for each type of microgreen. Further research related to the influence of lamp types on the content of useful phytochemicals is interesting to study.

Conclusion

There are differences in viability, first-day count and first- day of the leaves open among three genotypes of microgreen. Seed growth into microgreens has the same pattern of linear and positive. In dark conditions, the intensity of etiolation increases so that the microgreen is thin and pale yellow. The light color is specific to each type of microgreen. Red radish microgreen can be produced well on all tested colors, although there is a better tendency to red light. On the other hand, red amaranth is actually hampered under red light and coriander under white light. Blue lamps are recommended for increased yields of red amaranth and coriander microgreens.

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