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Influence of led supplemental lighting on aeroponic potato (*Solanum tuberosum L.*) minitubers production

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ABSTRACT

The photoperiod significantly regulates the growth and tuberization of a potato (Solanum tuberosum L.) transplanted inside a greenhouse grown aeroponically. Using a full spectrum LED grow light with 55% red (660 nm), 30% blue (450 nm), 15% other colors (5% of 6500K white, 5% of Infrared 730 nm, 5% of Ultraviolet 380 nm) illuminating 100 µmol/m²/s photosynthetic photon flux density (PPFD) on the granola potato cultivar, a 3-hour lighting supplementation, 6-hour lighting supplementation, and no lighting supplementation (natural daylength) were performed to investigate the effects on the growth and minituber production of potato plantlets. The supplemental lighting enhances height, increases stem diameter, and increases leaf size and the number of lateral stems. Compared to plantlets grown in natural daylight, the quality of the mini tubers increased by 51% in weight, 76% in diameter, and 21% in the average number of mini tubers per plant, offsetting the delayed stolon and tuber initiation. The results of this study suggest that a 3-hour lighting supplementation using full-spectrum LED lights is effective in propagating potato mini tubers. There is no significant difference between the 3-hour and 6-hour lighting supplementation in terms of minituber production; therefore, adopting the 3-hour regimen is more practical.

Contribution/Originality: Although aeroponics has been studied and practiced in developed countries, this study is unique in that it focuses on Benguet, Philippines, where most potatoes are produced. This research contributes to the existing body of literature; however, it is one of the very few studies conducted in the Philippines.

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1. INTRODUCTION

Potato is the fourth most valuable crop grown globally, behind only corn, rice, and wheat (Food and Agriculture Organization of the United Nations (FAO), 2015). The Philippines is among the top 104 countries in the world for potato production in 2021, with China being the largest producer, accounting for 25 percent of global production, amounting to 376 million metric tons (FAOSTAT, 2023).

Aeroponics systems could be one of the alternative methods for potato production, especially in urban areas where soil and water are in critical condition through in vitro conditions (Romanova, Khaksar, Novikov, & Leonova, 2019). The system significantly increases potato production compared with the other systems currently in use and protects them from pests and soil-borne diseases. Higher growth rates and robust, homogeneous, and healthy potato tubers are possible with aeroponics techniques. Aeroponic production has the potential to produce two to three times as many minitubers per plant compared to traditional methods (Rykaczewska, 2016).

Growing aeroponic potatoes in vitro may be more costly compared to systems under natural environmental conditions. Highland areas in the Philippines are the major producers of potatoes due to their favorable environmental conditions (Gonzales, Kiswa, & Bautista, 2016). Initial experiments proved that aeroponic potato production can be grown under greenhouse conditions. However, diurnal and seasonal variations, especially the natural photoperiod from the sun, can affect the growth and tuberization of potatoes (Schulz et al., 2019).

Plant physiology and growth are influenced by both the quantity (intensity and photoperiod) and quality (spectral composition) of light, which interact with other environmental parameters and cultivation factors to shape plant behaviors (Paradiso & Proietti, 2022). Using continuous light increased yields by providing plants with a substantial daily amount of light, but only when cultivars were physiologically capable of withstanding constant light (Wheeler & Tibbitts, 1987). Red and blue optical spectrums with wavelengths of 640-660 nanometers and 430-460 nanometers, respectively, are most effective for the growth of plants (Tertyshnaya & Levina, 2016). This was supported by the study of Paradiso et al. (2018), wherein the potato tuber yield was higher in plants under red and blue LED light (8:1 ratio) in both 'Avanti' and 'Colomba' potato cultivars. Conversely, red and blue LED light reduced stem elongation, the number and area of leaves, and the aerial biomass per plant in 'Colomba' compared to white, fluorescent tubes. Further, the red-blue-green LED light combinations in vitro on potato plantlets enhanced the weight and proportion of large tubers, as well as the number of tubers per plantlet (Chen et al., 2020).

According to Ishartati, Sukardi, Madiyanto, and Siskawardani (2017) potato plants yielded the most when they were transplanted and grew in the early stage under short days, which is believed to have begun with a significant number of tubers early in their growth, and then changed to sustained illumination, in experiments where they were transferred between environments to a 12-hour photoperiod and continuous lighting. However, based on (Rahman et al., 2021) the study, they followed 16 hours of light and 8 hours of dark, and 8 hours of light and 16 hours of dark, at the times of vegetative development and tuber bulking, respectively, employing artificial red (660 nm), blue (450 nm), far-red (730 nm), and white LED light.

To explore the responses of the granola potato cultivar, which is the commonly planted cultivar in the highland areas of the Philippines, we investigated the effects of different durations of full-spectrum LED light supplementation on growth and tuberization. Potato plantlets were transplanted through an aeroponic system installed inside a greenhouse under its natural environmental conditions, except for the photoperiod. Our results provide additional insights into the effects of LED light supplementation on potato plantlets grown under greenhouse conditions, which may improve the propagation of these plantlets.

2. MATERIALS AND METHODS

2.1. Plant Materials and Growth Conditions

The Granola potato cultivar was utilized in this study. It was acquired from the Northern Philippines Root Crops Research and Training Center, Benguet State University. The seedlings were propagated from microtubers and transplanted to the aeroponic growing chamber after 15 days in the nursery. The potato plantlets grow under natural environmental conditions. Based on data gathered by the instrument installed inside the greenhouse, a minimum of 100 $\mu mol/m^2/s$ PPFD from sunlight penetrates the greenhouse from around 8:00 am to 5:00 or 5:30 pm, resulting in an average of 9 hours of sunlight daily.

2.2. Aeroponic System

The aeroponic system, as shown in Figure 1, was installed inside a 4m x 7.5m greenhouse wrapped with a 50% shade net. The 200-liter HDPE plastic drum was used as the growing chamber for the aeroponic potato. Misting nozzles are installed in a downward position (Da Silva Filho et al., 2020) and operate for 30 seconds at 5-minute intervals (Based on our initial experiment).

Figure 1. Aeroponic setup inside the greenhouse.

2.3. Light Experiment Design

Light treatments included natural day length (no artificial lighting), 3 hours of LED lighting supplementation, and 6 hours of LED lighting supplementation. 30-watt full spectrum grow lights with 55% red (660 nm), 30% blue (450 nm), and 15% other colors (5% of 6500K white, 5% of infrared 730 nm, 5% of ultraviolet 380 nm) were utilized. Four LED grow lights were used per growing chamber, and the height was adjustable to meet the minimum light quantity of 100 μmol/m²/s PPFD (Rahman et al., 2021).

LED lighting supplementation was implemented during the early vegetative stage of the potato plant. It began on the first day of transplanting in the aeroponic growing chamber and concluded on the 35th day (5 weeks) after transplanting.

2.4. Plant Growth Parameters

Weekly plant heights were gathered until the 9th week. The plant height was maintained at an average of 80 cm through pruning (Andrade-Piedra, Kromann, & Otazú, 2019). Root length, development of stolons, and tuber development were observed and recorded.

2.5. Minituber Production

The production of minitubers, from the 4th week to the 17th week, was documented. Harvesting of minitubers was conducted at intervals of every 10-12 days (Andrade-Piedra et al., 2019). Harvested minitubers are dried at ambient temperature for a few hours and are classified by weight (International Potato Center, CIP) and diameter (Altaf, 2015).

2.6. Statistical Analysis

The study utilizes a Completely Randomized Design with three treatments and three replications. Each replication consists of six samples as shown in Figure 1. The data were analyzed with one-way analysis of variance (ANOVA) using JASP version 0.17.1.0 software. Tukey's test at the P

3. RESULTS

3.1. Growing Conditions

Potato seedlings were transplanted into the growing chamber of the aeroponic system in February 2024 and were terminated in June 2024. Using the Automatic Weather Station with a data logger, the temperature, relative humidity, and light quantity were recorded at 15-minute intervals. The average weekly data for temperature and relative humidity for the whole growing period is shown in Figures 2a and 2b. The temperature inside the aeroponic growing chamber ranges from 0.16 to 1.67 °C, which is higher than the temperature inside the greenhouse, and from 0.92 to 2.34 °C higher than the outside temperature. However, the aeroponic potato grows under its ideal growing temperature range from 15 to 25 °C (Otazu, 2010).

Figure 2b shows the relative humidity inside the greenhouse and outside. The relative humidity inside the aeroponic growing chamber was maintained at 90 - 100%. Figure 3 shows an example of a one-day, from 6:00 am to 6:00 pm, photosynthetically active radiation (PAR) curve penetrating inside the greenhouse. Table 1 shows the number of hours during which the potato plants inside the greenhouse receive greater than or equal to 100 μmol /m² /s of natural sunlight starting from the day of transplant until the 35th day. It shows an average of 8 hours and 30 minutes.

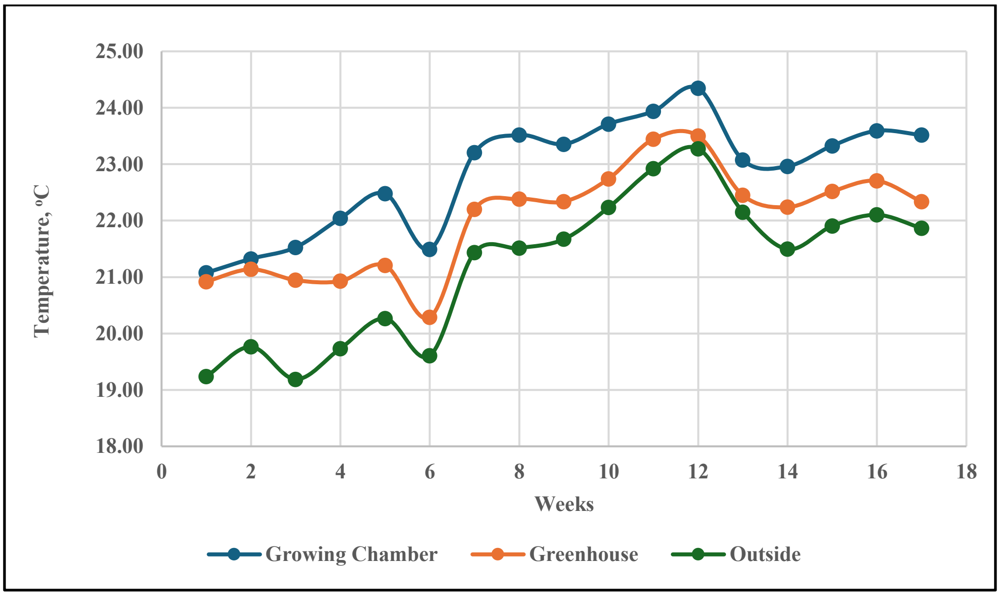

Figure 2a. Average weekly temperature inside the aeroponic growing chamber (Plant root zone), inside the greenhouse, and outside.

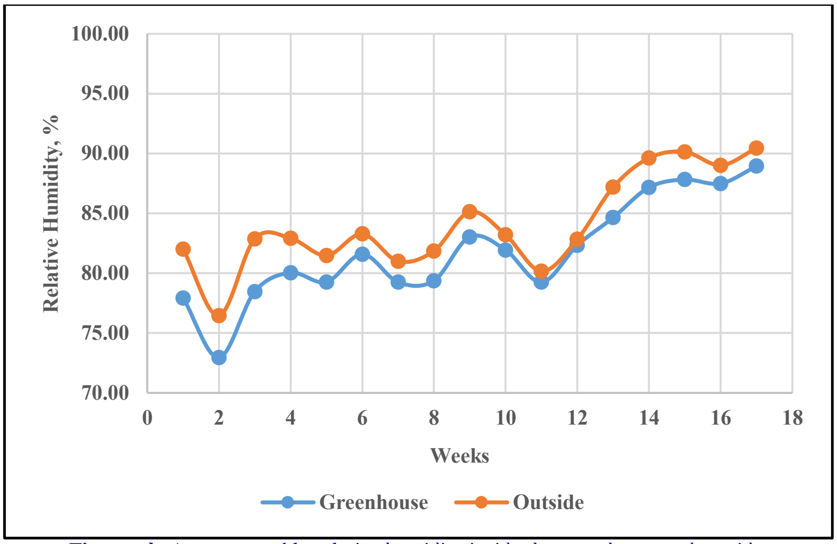

Figure 2b. Average weekly relative humidity inside the greenhouse and outside.

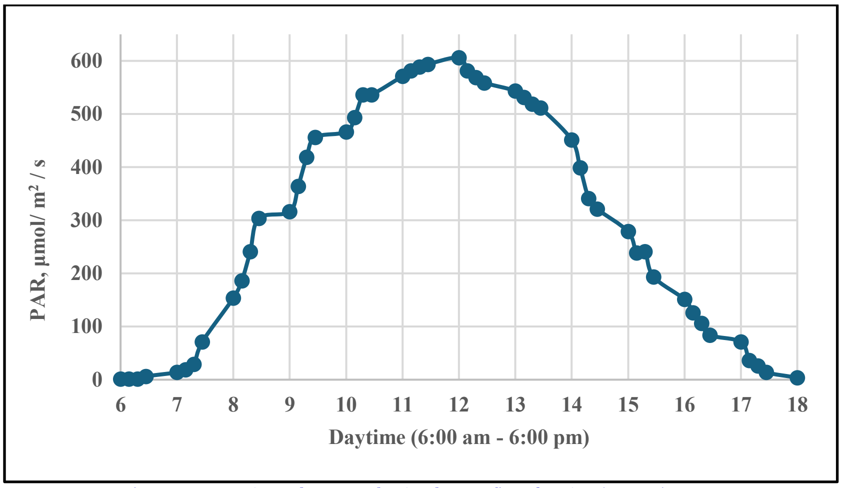

Figure 3. Daytime photosynthetic photon flux density (PPFD) curve.

Table 1. The number of hours that natural sunlight reaches the potato plants exceeds 100 µmol/m² /s.

Day	# of hours	Day	# of hours
1	8.00	19	8.75
2	8.25	20	8.25
3	8.00	21	7.00
4	9.25	22	8.75
5	8.00	23	8.50
6	6.75	24	9.50
7	7.50	25	8.50
8	9.25	26	9.00
9	9.00	27	8.25
10	8.75	28	8.00
11	8.75	29	7.75
12	8.75	30	8.25
13	8.75	31	7.75
14	7.50	32	8.75
15	8.25	33	8.75
16	7.50	34	8.00
17	9.00	35	9.50
18	8.75		

3.2. Growth of Potato Seedlings Under Different LED Lighting Durations

The different supplemental LED lighting duration significantly affects the growth of the potato, as shown in Figure 4. Treatments with lighting supplementation start to elongate more in the third week. The stem diameter and leaf area of the treatments with lighting supplementation were observed to be greater compared to the potato under natural lighting. The stem length of the potato plant with supplemental lighting can reach more than a meter if left unpruned, while the potato plant under natural lighting has reached only the maximum average length of 60 cm.

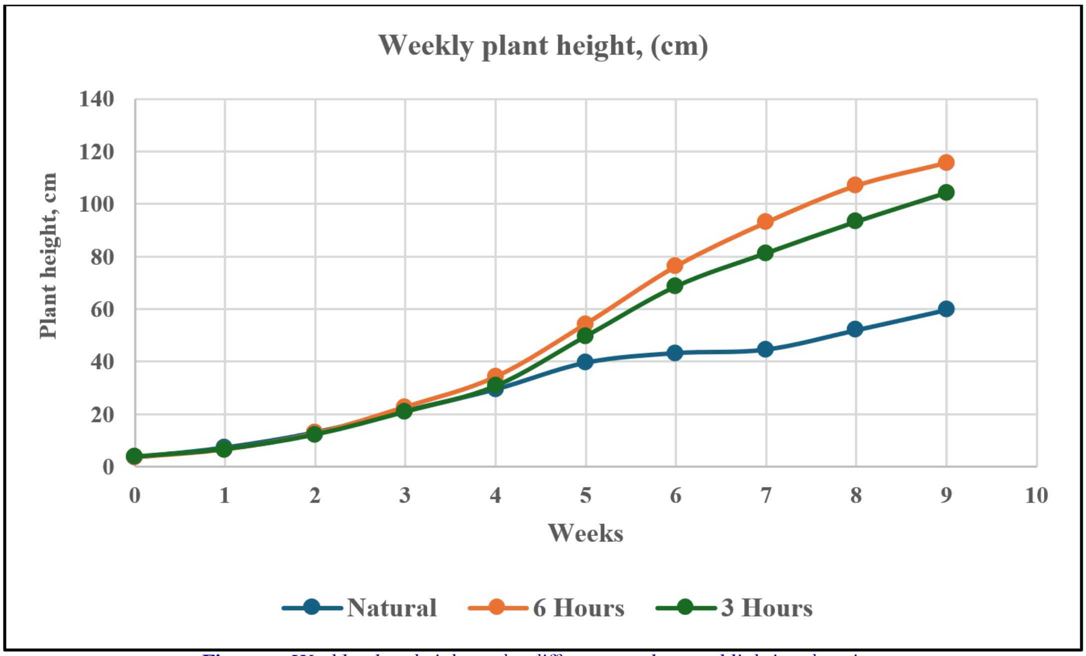

Figure 4. Weekly plant height under different supplemental lighting duration.

3.3. Stolon and Tuber Initiation

The supplemental lighting has a significant impact on the tuberization and lifespan of the granola potato. As summarized in Table 2, the stolon initiation until the termination of the plant is extended under the treatments with supplemental lighting. Seven harvesting frequencies were conducted under plantlets with no lighting and were terminated earlier compared to the plantlets with supplemental lighting, which delayed the harvesting of minitubers but prolonged the termination period. Only six harvesting frequencies were performed under plantlets with supplemental lighting; however, they produced better quality and a greater quantity of minitubers.

Table 2. Effects of the supplemental lighting on the stolon development and tuberization of the potato plant.

Effects on	Natural	6 hours	3 hours
Stolon initiation	Observed at 1 month DAT	delayed	delayed
Tuber initiation	Observed at 36 DAT	Delayed	Delayed
First harvest	44 DAT	63 DAT	53 DAT
Lifespan of plant	Dead plant was recorded on the 96 DAT	Extended	Extended

3.4. Tuberization Yield and Grading Performance

As shown in Table 3, the total number of harvested minitubers within the diameter class was affected by lighting. More microtubers (less than 5 mm) were observed on the stolons of plants with lighting; however, they fall short in the termination of the vegetative part needed to continue development. The same findings are observed when using classification by weight, as presented in Table 4. Supplemental lighting increases the minituber weight. The highest average number of minitubers per plant was recorded at 3 hours of supplemental lighting, followed by 6 hours, as presented in Table 5.

Table 3. Average number of minitubers gathered and graded per diameter (Altaf, 2015).

Light treatment	> 25 mm	20-25 mm	15-20 mm	10-15 mm	5-10 mm
Natural	1.67 *b*	11.67	42.00	62.00	13.34 *b*
6 hours	7.0 *a*	14.33	46.33	52.67	60.00 *a*
3 hours	5.0 *ab*	19.67	32.33	63.00	60.33 *a*

Table 4. Average number of minitubers gathered and classified according to weight (Based on the manual for seed potato production using Aeroponics produced by the International Potato Center (CIP) (Andrade-Piedra et al., 2019).

Light treatment	Production per weight class			
	> 10 g	5-10 g	2-5 g	<2 g
Natural	8.33 b	28.33	62.67	28.67 b
6 hours	15.33 a	27.67	57.67	81.00 a
3 hours	17.00 a	18.67	60.00	82.33 a

Table 5. Number and weight of minitubers gathered as affected by the supplemental lighting.

Light Treatment	Total Number of Minitubers (pcs.)	Average Number of minitubers per plant (pcs.)	Minimum Number of minitubers per plant (pcs.)	Maximum Number of minitubers per plant (pcs.)	Average Weight of Minitubers harvested per plant (grams)
Natural	140.60	23.44	16.60	33.00	93.47
6 hours	175.30	29.22	16.00	44.30	101.37
3 hours	177.00	29.5	13.68	54.60	107.34

Figure 5 illustrates the formation of the potato minitubers on the rootzone located inside the growing chamber. The harvesting of the seed potato minitubers is accessible through the aperture on the face of the cylindrical growing chamber. It further shows the grading by weight of harvested minitubers using the digital weighing scale.

Figure 5. Minituber production as affected by supplemental lighting.

4. DISCUSSIONS

4.1. Growth of the Potato Plantlets Analysis

The different durations of the artificial LED light full spectrum influence the growth and minituber development of the granola potato. The light with an average light quantity of 100 µmol /m² /s PPFD supplemented for 3 hours, and 6 hours has a significant difference in the growth of the potato plant grown in the natural daylight. Potatoes with supplemental lighting have a greater leaf area, larger stem diameter, and longer stem length. The plant's weekly height is shown in Figure 4. Potato plants grown under natural daylight reach a maximum average height of 60 cm, while those with supplemental lighting extend their height by more than a meter. The plant can reach a height of 2 meters if left untrimmed. Based on the results of our study, it supports the findings that blue light is essential for leaf expansion in the P. tricornutum plant (Schellenberger et al., 2013). The 30% blue (450 nm) light on the full spectrum grow lights we utilized in the study may have improved the potato plant leaves by enhancing cytokinins. Cytokinins significantly aid plant leaf development (Hwang & Sheen, 2001). Under blue light from fluorescent lamps, the highest concentration of cytokinins was found in a potato plantlet leaf grown in vitro under blue light spectrum fluorescent lamps (Sergeeva et al., 1994).

According to the other findings, potato plantlets growing in monochromatic red light had smaller, weaker, and slender leaves (Aksenova, Konstantinova, Sergeeva, Macháčková, & Golyanovskaya, 1994). However, our study supports the findings of (Rahman et al., 2021) wherein the potato plants developed longer stems and higher biomass. Our results are also consistent with the findings on in vitro potato plantlets grown under a 65% red + 35% blue light combination (Chen et al., 2020). The potato with supplemental full-spectrum lighting (55% red (660 nm), 30% blue (450 nm), and 15% other spectrum) enhanced the growth, biomass, and stem diameter.

In our study, the granola potato plant shows that the longer the photoperiod, the higher the growth rate. Studies have shown that complex photosynthetic machinery, utilizing photosynthetic pigments, captures light energy and converts it into chemical energy. Red and blue light are essential for photosynthesis and promote the production of chlorophyll and carotenoids (Fan et al., 2013). Our study is synonymous with the report, which found that long photoperiods increase stem weight and elongation more than short photoperiods. While the size of the leaves and leaflets decreases, there is an increase in both the quantity and weight of leaves (Haverkort, 2007).

4.2. Minituber Production Analysis

Extending the average nine hours of daylight with a minimum of 100 µmol m² /s PPFD to another six hours of LED light having 100 µmol m²/s PPFD resulted in more minitubers per potato plantlet as the same findings reported by Milinkovic, Horstra, Rodoni, and Nicolas (2012). As shown in Table 2 to Table 5, though the stolon and tuber initiation was delayed by the supplemental lighting (Haverkort, 2007), the supplemental lighting significantly improves the number of minitubers per plant, tuber weight, and tuber size. After being transplanted into a greenhouse, the red and blue LED lights and fluorescent lamp sources did not affect the number or size of tubers of Zantedeschia cultivar that were grown in vitro (Jao, Lai, Fang, & Chang, 2005). However, in our study, the effects of supplemental lighting at 6 hours and 3 hours, respectively, in addition to the natural day length, using a full-spectrum LED light on the early vegetative stage of the plantlets, are not consistent with the Zantedeschia potato plantlets. Instead, our findings are consistent with the study of Chen et al. (2020) on the effects of LED light spectrum on tuberization of potato plantlets in vitro utilizing the Zhongshu 5 potato cultivar. The reasons for these results may be the response of different genotypes to varying photoperiods. For example, the potato cultivars (Jemseg, Kathadin, Russet Burbank, and Superior) subjected to 8 hours of lighting resulted in the optimal treatment (Seabrook, Coleman, & Levy, 1993). Furthermore, our study is in contrast with the report that potato plants yield the most when they were transplanted and grow in the early stage under short days, which is believed to have begun with a significant number of tubers early in their growth, and then changed to a sustained illumination, in experiments where they were transferred between environments to a 12 hours photoperiod and continuous lighting (Ishartati et al., 2017). Instead, it is close to the recommendation to follow the 16 hours of light and 8 hours of dark, and 8 hours of light and16 hours dark, at the times of vegetative development and tuber bulking, respectively, employing artificial red (660 nm), blue (450 nm), far-red (730 nm), and white LED light (Rahman et al., 2021). Since the granola potato plantlets were grown in the same greenhouse environmental conditions in our study, we can infer that supplementation with full-spectrum LED light may affect the plantlets' photosynthetic capacities, which could be a significant factor in the tuberization performance of the plants. The supplemental lighting induced the axillary buds and developed into lateral stems. The proliferation of shoot branches could lead to the development of underground stolons, which is a requirement for tuber production (Tierno, Carrasco, Ritter, & De Galarreta, 2014). These could be the reasons why potato plantlets supplemented with LED lighting, which have longer stems and a higher number of lateral stems, resulted in increased quality in terms of size and weight, as well as a higher number of minitubers harvested per plantlet, compared to plantlets grown at natural day length. Based on the data, supplemental lighting at the vegetative stage delayed stolon and tuber initiation in exchange for improved minituber quantity and quality. Long days enhanced top plant growth, while short days were required to promote tuber production. As a result, tuber formation slowed to two to three weeks compared to the plantlets grown at natural day length. Tuber formation requires limitation of light penetration and darkness (Chang, Cho, Suh, Kim, & Lee, 2011; Chang, Park, Kim, & Lee, 2012). In comparison to proper illumination, an excess of light will promote shorter tuber growth (Mbiyu et al., 2012).

The weight and number of large tubers, as well as the average number of tubers per plantlet, increased in potato plantlets grown with supplemental lighting. Supplementing 3 hours of lighting in addition to natural daylight (a 12-hour average total photoperiod) can be utilized to propagate granola potato minitubers and other cultivars with similar characteristics, thereby improving tuberization performance.

5. CONCLUSION

The Philippines' potato farmers are dealing with issues related to soilborne diseases. The adoption of the aeroponic system cannot be fully introduced to the farmers due to the limited research conducted in the Philippine environmental settings. Most of the literature is conducted outside the country, which may produce different results for some findings. The results of this study, which improve the quantity and quality of minitubers produced per plant, may contribute to the country's potato production. Since this study was restricted to Benguet, Philippines, where potatoes are regularly farmed, related research on aeroponic potato production may be carried out in other potato-producing regions of the nation.

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