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ABSTRACT

While aeroponic systems have shown promise for seed potato production, light LED lighting, especially lights, remains largely unexplored. This study, therefore, aimed to uncover potential by determining the light compensation point (Ic) required for potato growth under LED lighting. Consequently, it could contribute to advancing the field of aeroponic farming, offering a promising future for sustainable agriculture.

The light compensation point is the irradiance where photosynthesis equals respiration, and it varies by species and environment. Selecting an appropriate light intensity is crucial for crop productivity and cost-efficiency. Limited research on potato cultivation under LED lighting is available, especially concerning plant photosynthetic rates. This study evaluated the effects of LEDs on potato plants, focusing on CO_2 exchange and biomass production.

Our results revealed valuable insights for aeroponic farming. For instance, we discovered that blue light was the most efficient for CO_2 absorption, with an Ic of ~50 µmol m^{-2} s^{-1}, while red light required 67 µmol m^{-2} s^{-1}. White and mixed lights exhibited higher Ic values (84.6 and 108.5 µmol m^{-2} s^{-1}, respectively). Plant exposure to blue light develops robust structures. Still, they had lower biomass than red treatments, underscoring the need for further optimization of LED spectra in aeroponic farming systems, thereby enhancing crop productivity and cost-efficiency.

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I. INTRODUCTION

Artificial light source is a critical component in indoor farming since light quality and intensity are one of the most important environmental factors affecting plant growth and morphology (Rabara et al., 2017) but also to prevail economically within the limits of plant growth and cost reduction (Domurath et al., 2012). The light compensation point is the irradiance at which the photosynthetic activity of a plant is equal to its respiratory activity by CO_2 exchange (Nobel, 2009), and it depends on species and growing environments (Taiz & Zeiger, 2002). So, it provides a basis for selecting light intensity suitable for developing a particular crop. Moreover, when we graph the Net Photosynthesis vs irradiance, the slope of the line at the light compensation point indicates quantum yield (φ), mol of CO_2 fixed by mol of photons irradiated (Long & Hällgren, 1993). It is also necessary to consider that 9 mol photons are required to fix a mol of CO_2 (Osborne & Geider, 1987). So, these measurements help better understand the effect of irradiance on crops.

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As an artificial illumination source, Light-emitting Diodes (LEDs) are the most popular for vertical farming or urban agriculture since they can emit a specific wavelength or a combination of them, they have a variety of designs, low heat emission, energy efficiency as well as their long lifetime (Janda et al., 2015; Rabara et al., 2017).

Potatoes are a highly productive crop, and tubers constitute an excellent source of carbohydrates and proteins. Field farming is associated with several risks and uncertainties in vital and environmental stresses, such as high winds, floods, droughts, and pest attacks (Tunio et al., 2020), and also the poor efficiency in the use of natural resources such as soil producing degradation on it and water waste (Lakhiar et al., 2018). Aeroponic culture is a soiless method that offers an innovative solution to ensure the environmental and economic sustainability of food supplies with high nutritional quality, nontoxic food, and labor (Lakhiar et al., 2018).

The potato (*Solanum tuberosum L*) is, due to its nutritional and energy value, an essential and necessary food in the diet of Mexicans, and its cultivation has excellent economic and social importance for many Mexican families (*NOM-041-FITO-2002*, 2003). One of the main challenges for the producers of this tuber is the quality of the plant propagation material, since the seed degenerates due to pathogens and diseases in the planting material continued in the cycles of vegetative propagation, affecting yields and the quality of the crop. The *in vitro* production of potato seed is very convenient since the seedlings are manipulated more easily to eradicate any pathogen present in the tissue (Tapia y Figueroa et al., n.d..). The pre-basic seed is obtained from *in vitro* plants that originate from the culture of meristems, and these can be used directly for the production of mini tubers (*ex vitro*) or the formation of microtubers (*in vitro*) (*NOM-041-FITO-2002*, 2003; Tapia y Figueroa et al., n.d..).

Potatoes are traditionally grown under open-field conditions, and fewer studies have been conducted on cultivation in a controlled environment illuminated with LEDs. The related lack of information in the literature excludes the benefits of LED or dichromatic light *on* potato plants or, particularly, the photosynthetic influence on tuberization.

Our research aimed to experimentally determine the minimum light necessary for growth in this culture. We tested photosynthetic rates in aeroponic potato culture under industry-relevant light intensities and various light qualities, measuring CO_2 leaf gas exchange. These experiments allowed us to determine the light compensation points (LCP) under different conditions, thereby proposing a suitable light intensity for growing *Solanum Tuberosum L.* aeroponic plantlets.

II. MATERIALS AND METHODS

2.1 Plant material, growth chamber, environmental conditions, and experimental design

Potato (*Solanum tuberosum L.)* variety Fianna plants *in vitro* were donated by the Plant Biotechnology Laboratory of the Instituto Tecnológico de Tlajomulco and transplanted *in vivo* in an aeroponic chamber divided into four zones. Each zone was isolated from any external light source and was illuminated for 10 days with white LED light by Philips HUE multicolor smart bulbs. After transplantation, 10 plants were allocated to each of the four light treatments and kept for the 8-week experimental period, Figure 1. The environmental conditions inside the growth chamber were set to a 12/12 h photoperiod. The energy provided by the LEDs in the chamber was fixed at 10.65 J m^{-2} s^{-1}, which means an irradiance of 61, 42, 51 and 48 μmol m^{-2} s^{-1} for the colors red, blue, 50% blue:50% red (mix) and white (33% blue, 32% green. 8% yellow, 15% orange and 12% red) respectively, measured with the limited by the technology of the HUE lamps for the blue light. Planck-Einstein's equation (6) was used to convert from PPFF to energy.

The Planck-Einstein equation relates the energy of a photon to its wavelength. It is expressed as:

$$E = h(\frac{c}{\lambda}) \tag{6}$$

Where:

- E is the energy of the photon (in joules).
- h is Planck's constant, approximately 6.626×10^{-34} J m^{2} s^{-1}
- c is the speed of light in a vacuum, approximately 3.00×10^{8} m s^{-1}
- λ is the wavelength of the photon (in meters).

Relative humidity 70 ± 10%, and temperature of 24 ± 1°C. Water spray irrigation was one minute every two hours. The plant nutrient solution was made with (meq/L) 10.5 of N, 11.6 of P, 9 of K, 6.1 of Ca, 1.1 of Mg, and 0.5 of S.

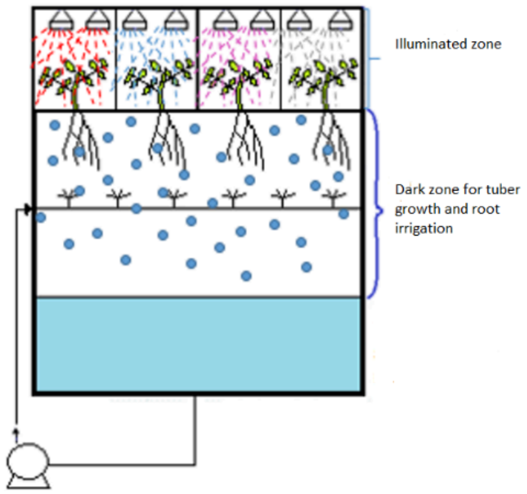


Figure 1: Aeroponic chamber scheme for potato growth

The experiment was performed twice for a randomized design of growth conditions.

2.2 Net photosynthetic rate determination

To determine the net photosynthesis, Pn, as the CO_2 measurements were made at 100 minutes of illumination, the Pn_{100}, not the total Pn for the plant. The equation proposed by Long & Hallgreen (1993) for closed systems was used:

$$Pn = \frac{C_1 - C_2}{(t_1 - t_2)} * \frac{V}{22.4} * \frac{P}{101.325} * \frac{273.15}{T*s} \tag{7}$$

Where:

Pn = Net photosynthetic rate (μmol m^{-2} s^{-1})
C = molar fraction CO_2 inside the cabin (μmol mol^{-1})
V = cabin's volume (L)
P = atmospheric pressure
S = leaf surface (m^{2})
t = time (h)

The Light Compensation Point, LCP, is obtained from the graph Pn vs irradiance for each treatment; more specifically, it is the point cross with the x axis. The slope at this point is called an apparent quantum yield, φ, and it indicates the amount of CO_2 fixed by mol of photons incident and not absorbed (Long & Hällgren, 1993).

2.3 Phenological monitoring

At the end of the treatment, each plant was measured to determine shoot length, shoot diameter, number of leaves, and root length. Plant tissue samples were dried in an oven for 48 h at 90°C before being weighed.

2.4 Statistical Analyses

Statistical analyses were carried out using the InfoStat Professional v.1.1 program. All the parameters were subjected to variance (analysis ANOVA) and a t-test. Differences were accepted as statistically significant when $P < 0.05$. Tuckey's test was carried out to identify significance among the samples.

III. RESULTS AND DISCUSSION

3.1 CO_2 Absorption at Different Light Intensities

Figure 5 presents the CO_2 absorption by the plants in the cabinet. The first 100 minutes correspond to measurements in the dark. The dotted lines indicate the boundary between dark and illuminated conditions. Overall, the results show that the higher the illumination, the higher the CO_2 absorption.

Under 10 PPFD, all treatments maintained a slope similar to mitochondrial respiration. We can see that even when photosynthesis has started, this light intensity is insufficient to disrupt the balance between the CO_2 absorbed via photosynthesis and the CO_2 produced by mitochondrial respiration. When exposed to 50 PPFD, only plants under blue light reached equilibrium (CO_2 absorbed = CO_2 produced). Plants treated with white and mixed lights reached this equilibrium at approximately 100 PPFD. Meanwhile, plants under red light required 100 PPFD to generate a positive CO_2 balance. Blue light proved the most efficient in facilitating CO_2 absorption, while red light was the least efficient.

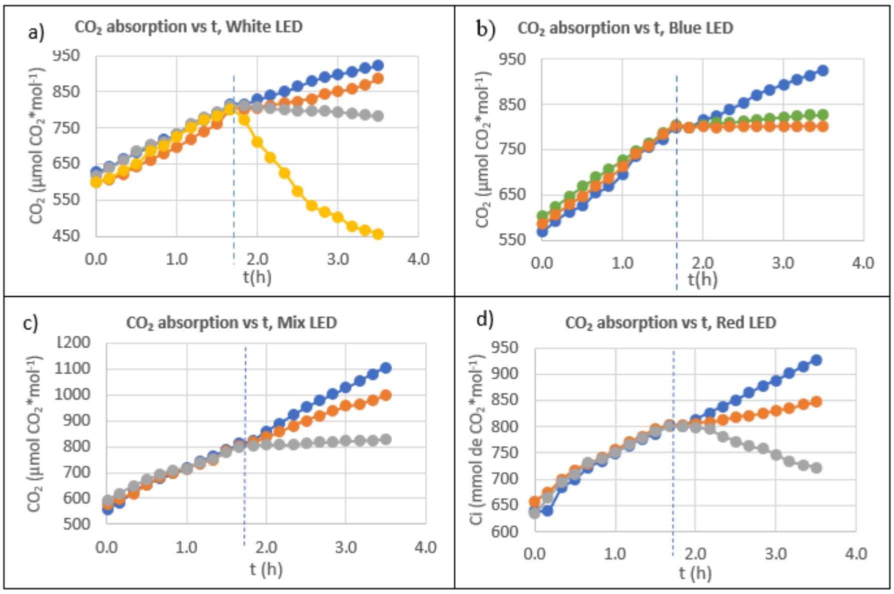
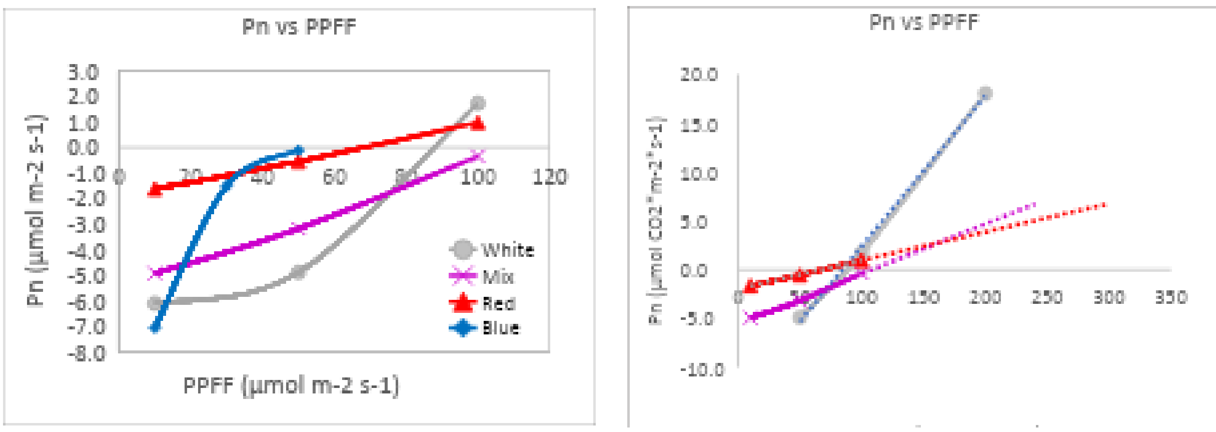


Figure 5: CO_2 absorption at different light intensity. CO_2 absorption vs time measured under a) white LED, b) blue LED, c) mix LED, and d) red LED. The blue line shows the CO_2 absorption by the plant to

10 PPFF, the green line to 30 PPFF to range line is the answer of the plant to illumination of 50 PPFF, gray line is the answer to 100 PPFF and yellow line to 200 PPFF. The vertical dotted lines indicate the beginning of the illumination.

3.2 Light Compensation Point and Quantum Yield

Figure 6 illustrates the relationship between net photosynthesis (Pn100) and light intensity for each treatment. Table 4 summarizes the light compensation point (LCP) and quantum yield (ϕ) calculated from these data. Blue light treatments achieved the lowest LCP (~50 μmol m² s⁻¹), significantly lower than white (84.6 μmol m² s⁻¹), mixed (108.5 μmol m² s⁻¹), and red light (67 μmol m² s⁻¹) treatments. Therefore, this suggests that blue light promotes higher photosynthetic efficiency under low light conditions, consistent with findings that highlight the role of blue spectra in enhancing CO_2 uptake and stomatal conductance (Li et al., 2017; Paradiso et al., 2019). The quantum yield was highest for white light (ϕ = 0.1543), followed by mixed, red, and blue lights. In contrast, plants under blue light operated near their LCP, which limited the calculation of a reliable quantum yield equation.



a) b)

Figure 6: a) Pn_{100} vs irradiance until 100 μmol $m^{-2} s^{-1}$, b) Pn_{100} vs irradiance until 200 μmol $m^{-2} s^{-1}$, showing the extrapolation lines and their equations at the LCP.

The light compensation point is mainly related to respiration and the light source used for the treatments (Azcón & Osmond, 1983). Due to the characteristics of this experiment, where dark respiration was established at 800 ppm, there are no other differences between the experiments, and calculated LCP was affected only by light source. Plants were grown in a light level close to the blue and red light compensation point. In this way, these plants grow and pass through the vegetative stage. Increasing the PPFD of light above the compensation point with these treatments is necessary to understand the light effect on biomass and the tuberisation process.

The light compensation point (LCP) (Table 4, Figure 5) was achieved at the lowest photon flux density with blue light (50 μmol $m^{-2} s^{-1}$), making it the most efficient for photosynthesis. Red, mix, and white light required higher fluxes (67, 84.6, and 108.5 μmol $m^{-2} s^{-1}$, respectively). The high efficiency of blue light correlates with its ability to increase stomatal conductance and net photosynthesis (Li et al., 2017). However, white light's quantum yield (Φ) was the highest among treatments, indicating its potential for efficient energy use once plants grow above the LCP. These results support further testing of white light under optimized conditions.

Table 4: Equations of the graphs Pn vs PPFF on light compensation

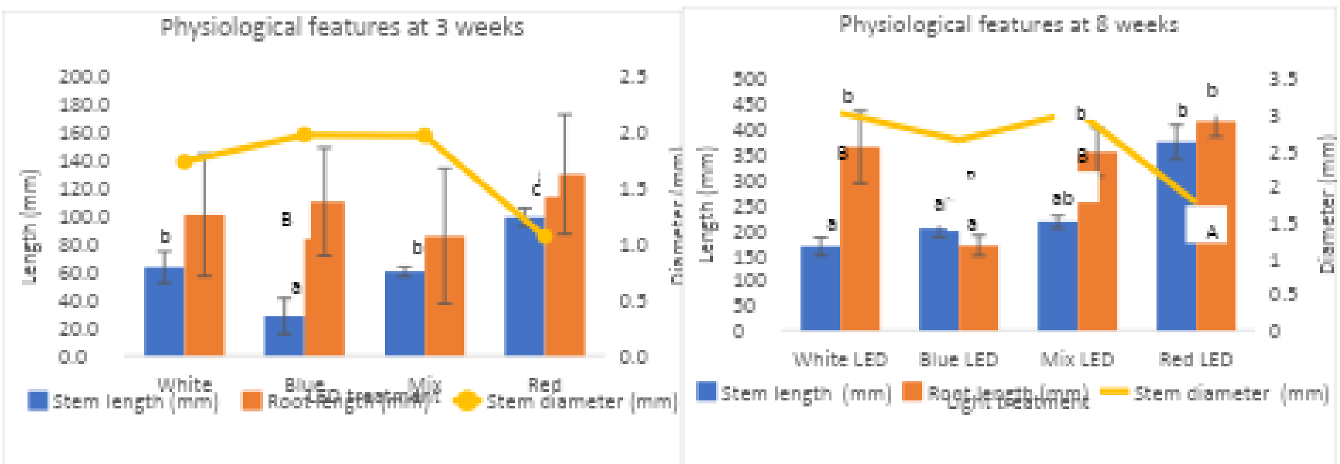
LED light treatment	Eq. Pn vs PPFF	LCP ($\mu mol\ m^{-2}\ s^{-1}$)	Φ ($\mu mol\ CO_2$/ μmol photon)
White	y= 0.1543x - 13.045 R^2= 0.997	84.6	0.1543
Blue	----	~50	---
Mix	y= 0.051x - 5.54 R^2 = 0.9948	108.5	0.051
Red	y= 0.029x - 1.94 R^2=0.9986	67	0.029

LCP, Light Compensation Point; φ, Quantum yield

3.3 Dry Biomass

The results in Figure 7 show that at three weeks, all plants developed longer roots than stems. At this stage, plants grown under red light displayed the longest roots, whereas those under mixed light had the shortest roots. In some studies made with *in vitro* plantlets, monochromatic red and far-red findings were stem elongation and leaf thinning in those seedlings producing fragile plants (Chen et al., 2020; Miyashita et al., 1995). This researcher found that blue light caused leaf expansion and increased leaf thickness (Chen et al., 2020) and hurt the growth of potato seedlings, but the plants were more robust and had broader leaves (Miyashita et al., 1995).. In our experiments, the same growth tendencies were observed in plants at three weeks of transplanting, However, at the end of eight weeks, these differences disappeared as observed in Figure 7b, mainly tainning only the thickness in stem and fragility for plants under red light treatment, which also showed the thinniest leaves. However, to compensate, plants increased the amount of leaf biomass, translating to a more significant number of leaves per plant.

Blue light produced the shortest roots at both time points, significantly smaller than other treatments.



a) b)

Figure 7: Physiological growth at week 4 (a) and eight weeks (b) after transplanting. The left axis refers to the length in mm for stems and roots. The right axis is reffered steam diameter. Data are presented as means ± standard error (n = 4). Different letters indicate significant differences between values ($p < 0.05$).

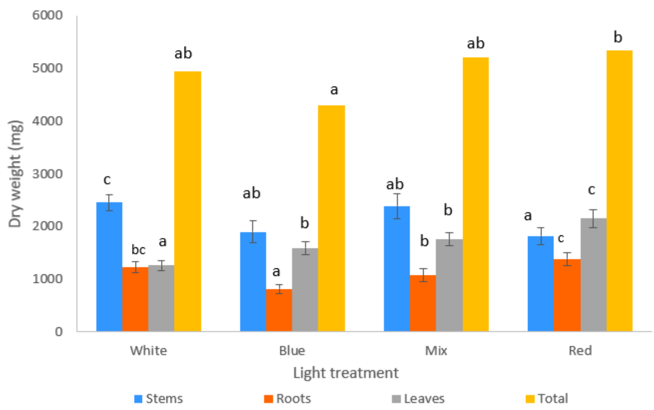


Figure 8: Dry weight of three plants after 8 weeks of light treatment at 10.65 J m^{-2} s^{-1}. Data are presented as means ± standard error (n = 4). Different letters indicate significant differences between values ($p < 0.05$).

IV. CONCLUSIONS

Solanum tuberosum L. plants derived from *in vitro* culture successfully grew in our aeroponic chamber illuminated with LED lights in blue, red, mixed (50:50 red and blue), and white spectrums over eight weeks. The findings highlight significant differences in the physiological responses of plants to varying light qualities and intensities. Blue light most efficiently achieved CO_2 equilibrium at the lowest light compensation point (~50 μmol m^{-2} s^{-1}), promoting robust plant structures. Red light, although less efficient, produced the highest foliar biomass. The mix and white light treatments required higher irradiance levels to reach the compensation point, yet they balanced structural development and biomass production.

These results indicate white and mixed light spectrums as promising candidates for further studies, particularly under conditions above their respective light compensation points. However, this study did not progress to the tuberization stage, a critical phase to validate the suitability of these light treatments for mini-tuber production. Future experiments should evaluate these light spectrums under various intensities above the compensation point to determine the optimum light conditions for maximizing tuber yield and quality. Based on these findings, we recommend using white light for future experiments due to its high Φ and mixed light for balancing energy use and biomass output. Further research should explore the impact of light intensities above the LCP to optimize growth and tuberization.

REFERENCES

1. Azcón-Bieto, J., Osmond, C.B. (1983). Relationship between Photosynthesis and Respiration: The Effect of Carbohydrate Status on the Rate of CO_2 Production by Respiration in Darkened and Illuminated Wheat Leaves. Plant Physiol. 71, 574–581. https://doi.org/10.1104/pp.71.3.574.
2. Chen, L., Zhang, K., Gong, X., Wang, H., Gao, Y., Wang, X., Zeng, Z., & Hu, Y. (2020). Effects of LED light spectrum on the growth, leaf anatomy, and chloroplast ultrastructure of potato plantlets in vitro and minituber production after transplanting in the greenhouse. *Journal of Integrative Agriculture*, *19*(1), 108–119. https://doi.org/10.1016/S2095-3119(19)62633-X.

3. Domurath, N., Schroeder, F.-G., & Glatzel, S. (2012). LIGHT RESPONSE CURVES OF SELECTED PLANTS UNDER DIFFERENT LIGHT CONDITIONS. *Acta Horticulturae*, *956*, 291–298. https://doi.org/10.17660/ActaHortic.2012.956.33.
4. Janda, M., Navrátil, O., Haisel, D., Jindřichová, B., Fousek, J., Burketová, L., Čeřovská, N., & Moravec, T. (2015). Growth and stress response in Arabidopsis thaliana, Nicotiana benthamiana, Glycine max, Solanum tuberosum, and Brassica napus cultivated under polychromatic LEDs. *Plant Methods*, *11*(1), 31. https://doi.org/10.1186/s13007-015-0076-4.
5. Lakhiar, I. A., Gao, J., Syed, T. N., Chandio, F. A., & Buttar, N. A. (2018). Modern plant cultivation technologies in agriculture under controlled environment: A review on aeroponics. *Journal of Plant Interactions*, *13*(1), 338–352. https://doi.org/10.1080/17429145.2018.1472308
6. Li, C.-X., Chang, S.-X., Khalil-Ur-Rehman, M., Xu, Z.-G., & Tao, J.-M. (2017). Effect of irradiating the leaf abaxial surface with supplemental light-emitting diode lights on grape photosynthesis: Supplemental light and grape photosynthesis. *Australian Journal of Grape and Wine Research*, *23*(1), 58–65. https://doi.org/10.1111/ajgw.12267
7. Long, S. P., & Hällgren, J.-E. (1993a). Measurement of CO2 assimilation by plants in the field and the laboratory. In D. O. Hall, J. M. O. Scurlock, H. R. Bolhàr-Nordenkampf, R. C. Leegood, & S. P. Long (Eds.), *Photosynthesis and Production in a Changing Environment* (pp. 129–167). Springer Netherlands. https://doi.org/10.1007/978-94-011-1566-7_9
8. Miyashita, Y., Kitaya, Y., Kozai, T., & Kimura, T. (1995). EFFECTS OF RED AND FAR-RED LIGHT ON THE GROWTH AND MORPHOLOGY OF POTATO PLANTLETS IN VITRO: USING LIGHT EMITTING DIODE AS A LIGHT SOURCE FOR MICROPROPAGATION. *Acta Horticulturae*, *393*, 189–194. https://doi.org/10.17660/ActaHortic.1995.393.22
9. Morrow, R. C., & Tibbitts, T. W. (1988). Evidence for Involvement of Phytochrome in Tumor Development on Plants. *Plant Physiology*, *88*(4), 1110–1114. https://doi.org/10.1104/pp.88.4.1110
10. Nobel, P. S. (2009). Leaves and Fluxes. In *Physicochemical and Environmental Plant Physiology* (pp. 364–437). Elsevier. https://doi.org/10.1016/B978-0-12-374143-1.00008-9.
11. *NORMA Oficial Mexicana NOM-041-FITO-2002, Requisitos y especificaciones fitosanitarios para la producción de material propagativo asexual de papa*. (2003). Diario Oficial de la Federación. http://dof.gob.mx/nota_detalle.php?codigo=698254& fecha=04/03/2003
12. Paradiso, R., Arena, C., Rouphael, Y., d'Aquino, L., Makris, K., Vitaglione, P., & De Pascale, S. (2019). Growth, photosynthetic activity, and tuber quality of two potato cultivars are affected by light source in a controlled environment. *Plant Biosystems - An International Journal Dealing with All Aspects of Plant Biology*, *153*(5), 725–735. https://doi.org/10.1080/11263504.2018.1549603
13. Rabara, R. C., Behrman, G., Timbol, T., & Rushton, P. J. (2017). Effect of Spectral Quality of Monochromatic LED Lights on the Growth of Artichoke Seedlings. *Frontiers in Plant Science*, *8*. https://doi.org/10.3389/fpls.2017.00190.
14. Taiz, L., & Zeiger, E. (2002). *Plant physiology* (3rd ed). Sinauer Associates.
15. Tapia y Figueroa, M. de L., Lorenzo, J. C., Escalona, M., & Mosqueda, O. (n.d.). Obtención de microtubérculos y minitubérculos como semilla pre-básica en tres cultivares peruanos de papa. *2017*, *17* (3), 153–159.
16. Tunio, M. H., Gao, J., Shaikh, S. A., Lakhiar, I. A., Qureshi, W. A., Solangi, K. A., & Chandio, F. A. (2020). Potato production in aeroponics: An emerging food growing system in sustainable agriculture for food security. *Chilean Journal of Agricultural Research*, *80*(1), 118–132. https://doi.org/10.4067/S0718-58392020000100118
17. Xu, Y. (2019). Nature and Source of Light for Plant Factory. In *Plant Factory Using Artificial Light* (pp. 47–69). Elsevier. https://doi.org/10.1016/B978-0-12-813973-8.00002-6.