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Original Paper

Effects of Various Hydroponic Systems in Increasing Caisim (*Brassica Chinensis L.*) Productivity Under LED Grow Light

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***Abstract*— Hydroponics has been proven to increase crop production, particularly for leafy vegetable families, significantly. In addition, the hydroponic system can assist farmers in managing water and nutrition; as a result, this method is appropriate for sustainability as a real action to prevent further environmental damage caused by agricultural production. Several hydroponics systems have been invented; however, to get high plant yields, a selection of the system must be done by looking at the characteristics of the cultivated plants. Furthermore, artificial environmental conditions, such as light, temperature, and humidity, must be adjusted to accommodate the plant's requirements in a closed hydroponic system. In this study, three hydroponics systems (i.e., wick technique, Nutrient Film Technique (NFT), and Deep Flow Technique (DFT)) were compared for morphology features, including the number of leaves, leaf width, plant height, wet root weight, and fresh weight. Caisim (Brassica chinensis L.) was grown on a single shelf; this design was intended to maximize land utilization in a closed area. Caisim's growing condition was under blue-red LED light for 35 days with a 16-hour illumination time at a distance of 15 and 20 cm. At harvest time, Caisim morphology utilizing the NFT approach produced a more significant (P < 0.05) result than the wick and DFT methods. Furthermore, on fresh weight, the LED at 15 cm outperformed the wick, DFT, and NFT at 20 cm by 20%, 47%, and 33%, respectively. According to the findings, the NFT approach combined with a 15 cm spacing distance or a light intensity of 250 PPFD was better and significantly impacted Caisim's shape.**

Keywords—- Hydroponics, Caisim (Brassica chinensis L.), Wick Technique, Nutrient Film Technique (NFT), Deep Flow Technique (DFT)

I. INTRODUCTION

The eviction of agricultural land for settlements and public facilities often occurs, along with the increase in population, causing a lack of space to grow crops. In 2030, the world will face a 1.8 – 2.4% cropland loss, especially in Asia and Africa [1]. At the same time, the demand for food continues to increase. As a result, most of today's agricultural performance depends on cultivating new regions to satisfy the food supply, which is difficult to be viable in the long term. Indeed, agricultural productivity must be raised faster than population expansion; however, this purpose must be done along with sustainability to prevent further environmental damage [2].

For this reason, alternative methods that can utilize small land with maximum yields are needed, especially around the urban area. Because shortly, approximately 50 – 63% of the newly expanded metropolitan area will occur [3]. The use of the hydroponic method has been proven to solve this problem. Other benefits of having a hydroponic system include allowing farmers to manage water and nutrient supply with up to 90% efficiency, and the farmer can get yield year-round [4][5]. Aside from that, hydroponics is a farming approach that can still be improved; its application is also simple to integrate with other systems such as fish farming (aquaponics), office areas, etc.

Hydroponic systems are generally defined depending on their air-water ratio; a) floated in the air, such as the wick technique, ebb & flow, and drip system, b) balanced air-water, like the nutrient film technique (NFT); and c) submerged in water, like deep flow technique (DFT). Overall, the a and b system groups are highly suitable for small plant cultivation, particularly vegetables. Meanwhile, the DFT method tends to be acceptable for the larger plant that produces fruits due to the plants being submerged in DFT nutrients, improving plants' absorption and increasing cell growth rate [6]. At the same time, hydroponic techniques can also be categorized based on water distribution, such as continuous circulation and non-circulation [7]– and the wick technique is the only one designated as a non-circulation orientation system. However, because not all plants are adaptable, not all hydroponic techniques can be used; consequently, a planting system capable of maximizing plant growth abilities is required.

The hydroponic techniques can be installed using semi-closed and closed farming systems. However, in order to achieve an urban farming system in limited space, then the closed room in a building must be exploited and require the farmers to change and adapt to the cultivation condition, especially the light sources. It is essential to meet the plant's light requirement because the plant can't function its photosynthesis apparatus properly in lower light intensity, causing etiolation and reducing the growth rate of the plant [4]. Currently, the light-emitting diode (LED) light source has attracted much attention from hydroponic farmers due to the specific spectrums provided around 450 nm (blue) and 660 nm (red), which highly influence plant morphology and photosynthesis, respectively. As an essential environmental factor, artificial light sources can replace sunlight, even at a higher efficiency level [8]. However, excessive light illumination can initiate photoinhibition and trigger reactive oxygen species. As a result, the positioning of the light resource is highly essential to plant growth.

Brassica Chinensis L., famous as caisim, played a role as the object in this study. This plant contains many beneficial substances for human health, such as protein, carbs, calcium (Ca), phosphorus (P), fat, vitamins A, B, and C, etc. Furthermore, Caisim has a pleasant flavor and may be easily mixed with other foods, as evidenced by the total production of more than 250 million tons through 2020 (included in the cabbage and brassica families), which indicates that people's desire for this vegetable is very high [9]. Caisim cultivation hydroponically is a relatively easy method by consistently giving water and fertilizers and maintaining moisture; thus, the Caisim plant will grow normally. However, in order to increase plant yields, the hydroponic system must be carefully selected. A side-by-side comparison of hydroponic techniques and soil-grown lettuce under the same environmental circumstances revealed no discernible changes in terms of morphological features; this lettuce investigation using the wick method combined with an aerator [10]. On the other hand, plant yield tends to be superior under conditions of adequate hydroponic techniques when compared to the soil-grown method [11].

Based on the present conditions, it is possible to conclude that the combination of hydroponic types and lighting distance is highly influential in achieving higher yields in closed farming conditions. Although the effects of hydroponic systems and lighting distance have been described for many leafy vegetables. However, only a few studies have been conducted on the Caisim (Brassica Chinensis L.). Consequently, this study aims to reveal the type of hydroponic system and the best spacing of LED grow lights for the growth of caisim plants. This study deployed three types of hydroponics: wick, NFT, and DFT, with lighting distances of 15 and 20 cm. For 35 days, the morphology of caisim plants will be measured, such as (the number of leaves, plant height, leaf width, weight of wet roots, and fresh weight). The results of each hydroponic system were compared using a two-way ANOVA technique and Tukey's test with 95% confidence level ($p < 0.05$).

II. METHODOLOGY

A. Hydroponic System Installation

Hydroponic systems were built on one single shelf with four levels of the wick, DFT, and NFT techniques and containers for nutrition on the lowest level. Figure 1 shows two heights at each level, which were assigned for two different light source distances (i.e., 15 and 20 cm). Illumination purposes on the plant were done using LED red-blue of 3:1 ratio with 30 watts during all cultivation stages. Additionally, the light intensity of the red-blue LED based on the product specification was approximately 350 µmol m^{-2} s^{-1} (PPFD). Two pumps were deployed to circulate water and nutrition from the container for DFT and NFT techniques. Those pumps were combined with aerators to enrich the circulation with oxygen (O_2). Because it is rich in nutrients, the system pipe NFT and DFT hydroponics are easy to grow moss; these pipes should be cleaned regularly for 4 to 5 days. Meanwhile, the wick system's water and nutrition were uncirculated; stirring the solution was essential to prevent precipitation.

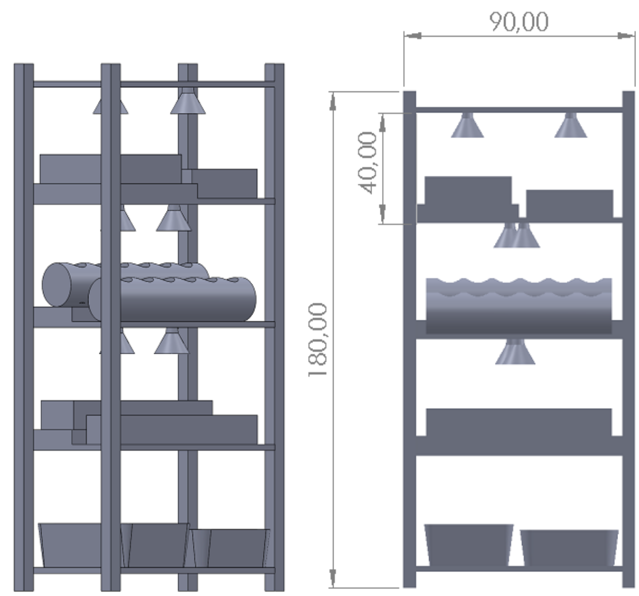

Fig 1. Hydroponic system installation design.

B. Cultivation Condition

Caisim seeds (Brassica chinensis L.) were sown in a germination tray with rock wool as the medium, and each rock wool contained 3-4 seeds of caisim. During the sowing stage, caisim seeds were watered, nourished, and illuminated under 15 and 20 cm artificial light following 16 hours of light photoperiod [12]. Light intensity values on the shelf for 15 and 20 cm varied around 250 and 150 PPFD, respectively, through the whole experiment, and it was measured using a lux meter.

After 10 days after sowing (10 DAS), 36 uniforms caisim were picked and transplanted into hydroponic systems with the same illumination condition. In detail, each hydroponic system contained 6 caisim plants, which meant 3 plants per light distance, and was repeated twice. In the growing stage, nutrition was changed each week at different concentrations; the first day after transplanting (DAT), 10, 20, and 30 DAT were 500, 800, 1000, and 1300 ppm, respectively—nutritional value adjusted to the needs of plants. In this study, AB mix nutrition for leafy vegetables had been used during the whole cultivation stage, which provided macro (N, P, K, Ca, Mg, and S) and micro (Fe, Mn, B, Zn, Cu, and Mo) nutrients.

The number of nutrients and the pH of the circulating water are very significant, so it is critical to perform periodic checks to avoid pH changes and nutrition deficiency. TDS and EC meters were employed in order to maintain nutritional value, with TDS values regulated according to crop time and EC values ranging from 0.8 to 1.2 mS/cm. In addition, using a pH meter, the pH value is in the range of 5.5 to 6.5 [13]. The schematic procedure of the experimental setup for caisim cultivation is shown in figure 2.

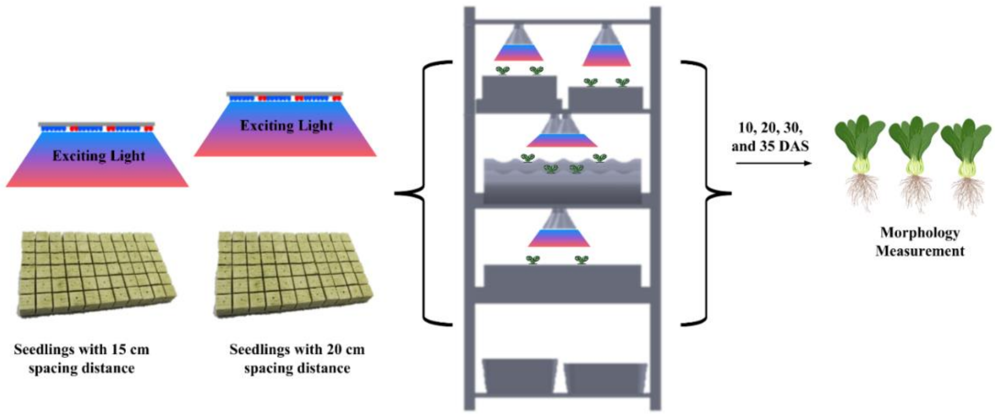

Fig 2. Schematic of the experimental setup of Caisim cultivation.

C. *Plant Measurement and Data Analysis*

Caisim was moved every 10 days to measure growth parameters, such as the number of leaves, leaf width, plant height, wet root weight, and fresh weight. The growth parameters assessment was conducted at 10, 20, 30, and 35 days. The longest leaf was selected as a representative of leaves for leaf width measurement. Then, the plant height was calculated by including roots in rock wool. The roots were gently dried with tissue after being washed in water to eliminate algae from the surface. Before removing the plant's leaves and roots, the height and length of the plant were measured. Plant roots and shoots were measured independently. The obtained data were analyzed using a two-way ANOVA technique with lighting distances and hydroponic systems and Tukey's test with a 95% confidence level ($p < 0.05$) [14]. The results were compared to find the best treatment for caisim cultivation.

III. RESULT

The growth condition of caisim is shown in figure 3. The environmental conditions were created to fulfill the plant's needs, with a temperature of 24 - 28 ^{0}C and a water pH of 6 - 6.5. This study used rock wool as a medium, with advantages such as ease of handling and nutrient management in plants. This medium's essential advantage is its low density and inertness, making plant roots easy to expand [15]. Those benefits could be worked well with hydroponic methods.

The morphological features of the number of leaves, plant height, leaf width, and weight of wet roots are shown in Table 1. Although some of the results were not statistically different, from the perspective of lighting distance, the 15 cm LED had more leaves and larger plants (in terms of height and width) than the 20 cm. In addition, based on hydroponic systems perspective (figure 4), The NFT technique produced more leaves and bigger plants and the roots of this technique was also larger than those of the other techniques, even up to twice the size of the wick system.

Fig 3. Growing condition of caisim plants

IV. DISCUSSION

Based on the caisim morphology results, the NFT plants were continuously extending their root systems during the cultivation processes in order to reach water resources. In contrast, the DFT and wick systems tended to have shorter root systems, which was affected by the irrigation system– plants of both systems had a direct water supply to their root area. According to a reference, the system with more excellent root aeration can promote plant growth rate better; however, frequent exposure to the nutrient solution is also an essential factor [16].

In this study, the air-water ratio of the NFT system has fulfilled all key conditions to grow caisim optimally. The air-water ratio of the wick system was set to fill the space of about 3.800 liters and was sufficient to cover the entire root area of the plant, especially near harvest day, when the root area of the plant sank more. While at the NFT and DFT systems, the water was circulated through the system by a pump of 3.200 liters per hour. Furthermore, the air-water ratio of the NFT system was well suited due to the degree of inclination in the chamber's system.

A specific case occurred in plant height on the wick system on harvest day, at 15 cm on harvest time– employing the wick approach has a bigger value (10 cm) than DFT (8.9 cm), comparable to the NFT method of 10.25 cm. Noteworthy, the DFT method combined with the 15 cm light condition had inconsistent results, where the leaf width and plant height were inversely related. It might indicate etiolation, characterized by plant height that differs from proportion to leaf size [17].

TABLE I. MORPHOLOGY OF CAISIM GROWN IN NFT, DFT, AND WICK SYSTEMS (DAY 35).

Parameters	NFT		DFT		Wick System	
	15 CM	20 CM	15 CM	20 CM	15 CM	20 CM
Fresh Weight (g)	57.45[a*]	43.4[b*]	50.65[a*]	34.6[b*]	36.75[a]	31.1[a]
Number of leaves	20[a]	18[a]	19[a]	17.5[a]	17[a]	16[a]
Plant height (cm)	33.75[a*]	29[b*]	32.25[a*]	29.25[b*]	27.5[a]	28.75[a]
Leaf width (cm)	10.25[a*]	7.75[b*]	8.9[a*]	7.9[b*]	10[a*]	6.75[b*]
Weight of wet roots (g)	4[a*]	3[b*]	2.55[a]	2.4[a]	1.9[a]	1.9[a]

a; b us the rank from Tukey test result; * Significantly different ($p < 0.05$).

Assessed from the perspective of the light distances (table 1), the 15 cm spacing with the plant object gave superior results than the 20 cm spacing. Many studies have evidenced that the LED with an R:B ratio positively influenced cultivating plants [18] and in the case of caisim plants [19]. In fact, both monochromatic red light and blue light are ineffective for hydroponic lettuce production in PFAL in terms of yield; hence, combining red and blue light are essential spectral qualities for crop cultivation in a closed farming system [20]. LED light sources are also excellent in terms of long-term performance, reasonably high electricity-to-light conversion, and, most importantly, the surface temperature is pretty low, so it does not significantly affect the ambient temperature [21].

The light source intensity positively impacts plant development; the more light intensity, the better the plant morphology. In this case, the light intensity was appointed as PPFD or in a µmol m^{-2} s^{-1} value. However, the light intensity with a PPDF value above 300 µmol m^{-2} s^{-1} was indicated with no substantial gain on plant growth in cases of sweet potato and tomato plants [22][23]. In this study, the wick system comes out with unaffected light distance to the morphological features of cultivated plants on the outcome. Generally, the 15 cm distance of the wick system has a better result, even though it is not statistically significant. This finding was consistent with Kuankid and Aurasopon's study, which found that lettuce (leafy vegetable) grown in a wick system with a higher PPFD exposure value had better morphological characteristics than lettuce produced in a wick system with a lower PPFD exposure value [24]. Thus, a light treatment that can significantly impact morphological plant features with low energy and heat is highly recommended. Besides mentioned aspects, such as the quality and intensity of light sources, light's illumination duration also influences plant growth. In some circumstances, a plant's demand for light varies significantly. Changing the photoperiod dramatically affects plant growth [12][25].

It has been found that plant development is influenced by the relationship between the number of leaves and the plant's photosynthetic capacity [12]. The plant has a greater ability to absorb energy from the light source along with the quantity of photosynthesis apparatus. This interaction can be seen in the number of leaves (table 1); as a result, figure 4 presents the fresh shoot of the Caisim. Plants under the NFT technique have 20 leaves at harvest, and their fresh shoot is more fulfilling than plants with fewer leaves. Similar results were observed in Kang *et al.* research; the number of leaves not only influenced the weight of the plant but also affected the overall morphological traits, including plant height and root length [25]. Caisim fresh weight gradually increases in the order of the wick system < DFT < NFT. Lastly, the NFT technique produced the heaviest Caisim product on harvest day, followed by DFT and wick system with a better vegetable. The 20 cm spacing distance was the same; the variation isn't as noticeable during the cultivation stages. Additionally, providing nutrients in higher dosages, but not excessively and accurately, may benefit hydroponic agricultural systems. According to a study on paddy, using nutrients can increase plant quality in terms of appearance [26].

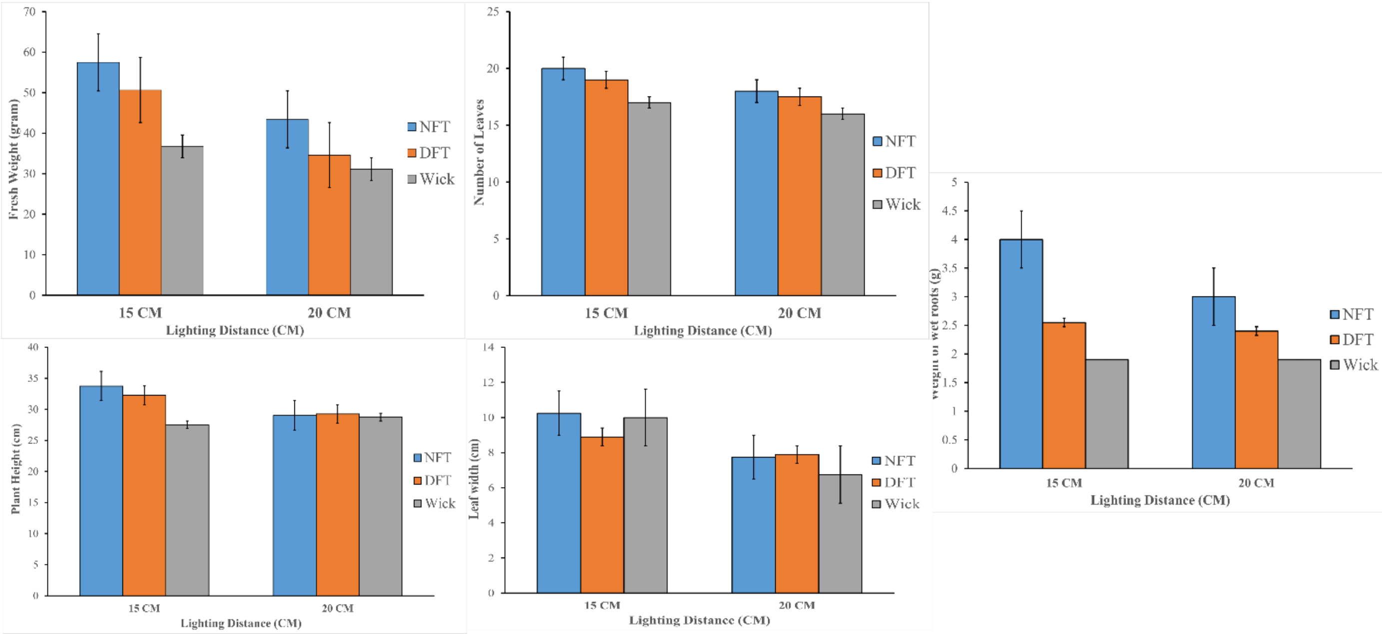

Fig 4. Morphology of caisim samples in 15 cm spacing distance and 20 cm spacing distance. Treatments with at least one common letter are not have a significant difference.

Based on the consumer perspective, the buyer considers having fresh, hygienic, and free-pesticide leafy vegetables from hydroponic products [27][28]. Hence, hydroponic products will always be acceptable in the market due to the quality produced. The consumer statement indicates they prefer quality over the price concept; however, more consumers would pick the price over the quality concept. Thus, it may be inferred that consumers choose plant products with higher quality at the same price, including the fresh weight of the plant. Apart from plant appearance, a comparison study on plant sensory qualities between hydroponic and conventional systems showed that different production systems do not generate significant sensory differences in leafy green vegetables [29]. As a result, referring to the commodity's outward look will reduce the consumer's purchasing power. Additionally, profitable industries like hotels and restaurants choose hydroponic plants. Higher net-weight products are favored since they may use more plant parts [30].

CONCLUSIONS

In summary, morphological traits of plants grown using different hydroponic techniques side-by-side in the same environment showed apparent disparities. The NFT-grown caisim had the highest fresh weight on the harvest day, followed by DFT and wick systems. The air-water ratio of the NFT method can precisely meet the needs of Caisim plants. At the same time, hydroponic systems with a 15 cm spacing distance above the cultivated plants exhibited a remarkable result on the fresh shoot of Caisim, which illuminated 250 µmol m^{-2} s^{-1} (PPFD). On the other hand, the 20 cm spacing distance only delivered 150 PPFD; hence, the energy provided is insufficient to help plants grow optimally. The NFT system may be used with an irradiation distance of 15 cm or with an incoming light PPFD value of 250 µmol m^{-2} s^{-1} to attain Caisim productivity. However, many parameters are needed to measure; thus, the result can become more reliable.

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REFERENCES

[1] C. B. D'Amour, F. Reitsma, G. Baiocchi, S. Barthel, B. Güneralp, K. H. Erb, H. Haberl, F. Creutzig, and K. C. Seto, "Future urban land expansion and implications for global croplands," (2017), *Proc. Natl. Acad. Sci. U. S. A.*, vol. 114, no. 34, pp. 8939–8944, [Online].

[2] D. Frona, S. Janos, and M. Harangi-Rakos, "The challenge of feeding the poor," (2019), *MDPI J. Sustain.*, no. 2017, pp. 3–4.

[3] G. Chen, X. Li, X. Liu, Y. Chen, X. Liang, J. Leng, X. Xu, W. Liao, Y. Qiu, Q. Wu, and K. Huang, "Global projections of future urban land expansion under shared socioeconomic pathways," (2020), *Nat. Commun.*, vol. 11, no. 1, pp. 1–12,

[4] F. A. Khan, "A Review an Hydroponic Greenhouse Cultivation for Sustainable Agriculture," (2018), *Int. J. Agric. Environ. Food Sci.*, vol. 2, no. 2, pp. 59–66, [Online].

[5] K. Degefa, G. Biru, and G. Abebe, "Factors Affecting Tomato Productivity in Western Oromia, Ethiopia: Evidence from Smallholder Farmers," (2022), *Int. J. Food, Agric. Nat. Resour.*, vol. 3, no. 2, pp. 5–10, [Online].

[6] S. Jan, Z. Rashid, T. A. Ahngar, S. Iqbal, M. A. Naikoo, S. Majeed, T. A. Bhat, R. Gul, and I. Nazir, "Hydroponics – A Review," (2020), *Int. J. Curr. Microbiol. Appl. Sci.*, vol. 9, no. 8, pp. 1779–1787, [Online].

[7] N. Sharma, S. Acharya, K. Kumar, N. Singh, and O. P. Chaurasia, "Hydroponics as an advanced technique for vegetable production: An overview," (2018), *J. Soil Water Conserv.*, vol. 17, no. 4, p. 364, [Online].

[8] E. Ruangrak and W. Khummueng, "Effects of artificial light sources on accumulation of phytochemical contents in hydroponic lettuce," (2019),

J. Hortic. Sci. Biotechnol., vol. 94, no. 3, pp. 378–388,

[9] FAO, "Agricultural Production Statistics: 2000-2020," (2021), *FAOSTAT Anal. Brief-41*, vol. 1, no. 1, p. 1,

[10] C. Lei and N. J. Engeseth, "Comparison of growth characteristics, functional qualities, and texture of hydroponically grown and soil-grown lettuce," (2021), *Lwt*, vol. 150, no. May, p. 111931,

[11] P. Sukprasert, "Hydroponic vegetable cultivation development for extension at Luk Phra Dabos Agricultural Training and Development Center , Samut Prakan province," (2018), vol. 4, no. December 2016, pp. 106–119.

[12] X. Zhang, D. He, G. Niu, Z. Yan, and J. Song, "Effects of environment lighting on the growth, photosynthesis, and quality of hydroponic lettuce in a plant factory," (2018), *Int. J. Agric. Biol. Eng.*, vol. 11, no. 2, pp. 33–40, [Online].

[13] H. S. Chua, L. S. Wei, S. Paramasivam, T. T. Goh, and G. C. Chen, "Effect of artificial night lighting on the growth of loose head lettuce in hydroponic system," (2020), *Sains Malaysiana*, vol. 49, no. 12, pp. 2891–2900, [Online].

[14] P. Singhal, R. Singh, S. Satya, and S. N. Naik, "Changing Consumption Patterns of Bamboo shoots: A Case Study of Traditional Food-Related Knowledge Systems," (2022), *Int. J. Food, Agric. Nat. Resour.*, vol. 3, no. 3, pp. 1–4, [Online].

[15] R. S. Velazquez-Gonzalez, A. L. Garcia-Garcia, E. Ventura-Zapata, J. D. O. Barceinas-Sanchez, and J. C. Sosa-Savedra, "A Review on Hydroponics and the Technologies Associated for Medium-and Small-Scale Operations," (2022), *Agric.*, vol. 12, no. 5, pp. 0–21, [Online].

[16] Q. Li, X. Li, B. Tang, and M. Gu, "Growth responses and root characteristics of lettuce grown in Aeroponics, Hydroponics, and Substrate Culture," (2018), *Horticulturae*, vol. 4, no. 4, [Online].

[17] A. H. Calori, T. L. Factor, S. Lima Júnior, L. A. S. Moraes, P. J. R. Barbosa, S. W. Tivelli, and L. F. V. Purquerio, "Condutividade elétrica e espaçamento sobre a produção de baby leaf de beterraba e alface," (2014), *Hortic. Bras.*, vol. 32, no. 4, pp. 426–433, [Online].

[18] J. He, L. Qin, Y. Liu, and T. W. Choong, "Photosynthetic Capacities and Productivity of Indoor Hydroponically Grown Brassica alboglabra Bailey under Different Light Sources," (2015), *Am. J. Plant Sci.*, vol. 06, no. 04, pp. 554–563, [Online].

[19] Y. Li, N. Liu, F. Ji, and D. He, "Optimal red:blue ratio of full spectrum LEDs for hydroponic pakchoi cultivation in plant factory," (2022), *Int. J. Agric. Biol. Eng.*, vol. 15, no. 3, pp. 72–77, [Online].

[20] W. Liu, L. Zha, and Y. Zhang, "Growth and nutrient element content of hydroponic lettuce are modified by LED continuous lighting of different intensities and spectral qualities," (2020), *Agronomy*, vol. 10, no. 11, pp. 1–11, [Online].

[21] T. Kozai, K. Fujiwara, and E. S. Runkle, "LED lighting for Urban agriculture," (2016), *LED Light. Urban Agric.*, pp. 1–454, [Online].

[22] D. He, Z. Yan, X. Sun, and P. Yang, "Leaf development and energy yield of hydroponic sweetpotato seedlings using single-node cutting as influenced by light intensity and LED spectrum," (2020), *J. Plant Physiol.*, vol. 254, no. May, p. 153274,

[23] L. Promratrak, "The effect of using led lighting in the growth of crops hydroponics," (2017), *Int. J. Smart Grid Clean Energy*, vol. 6, no. 2, pp. 133–140, [Online].

[24] S. Kuankid and A. Aurasopon, "The Effect of LED Lighting on Lettuce Growth in a Vertical IoT-Based Indoor Hydroponic System," (2022), *Int. J. online Biomed. Eng.*, vol. 18, no. 7, pp. 70–84, [Online].

[25] J. H. Kang, S. KrishnaKumar, S. L. S. Atulba, B. R. Jeong, and S. J. Hwang, "Light intensity and photoperiod influence the growth and development of hydroponically grown leaf lettuce in a closed-type plant factory system," (2013), *Hortic. Environ. Biotechnol.*, vol. 54, no. 6, pp. 501–509, [Online].

[26] B. T. W. Putra, W. N. H. Syahputra, Rusdiamin, Indarto, K. Anam, T. Darmawan, and B. Marhaenanto, "Comprehensive measurement and evaluation of modern paddy cultivation with a hydroganics system under different nutrient regimes using WSN and ground-based remote sensing," (2021), *Meas. J. Int. Meas. Confed.*, vol. 178, no. January, p. 109420,

[27] P. C. Ayu, R. B. M. I. Fathoni, and R. R. Siregar, "Indicators of customers in selecting hydroponic green leafy vegetables (Study case: Millenials in North Sumatera)," (2021), *IOP Conf. Ser. Earth Environ. Sci.*, vol. 782, no. 2, [Online].

[28] C. Gunden and T. Thomas, "Assessing consumer attitudes towards fresh fruit and vegetable attributes," (2012), *J. Food, Agric. Environ.*, vol. 10, no. 2, pp. 85–88.

[29] K. Dhakal, R. Ravi, and D. Nandwani, "Comparative Study of Sensory Attributes of Leafy Green Vegetables Grown Under Organic and Conventional Management," (2021), *Int. J. Food, Agric. Nat. Resour.*, vol. 2, no. 3, pp. 29–45, [Online].

[30] K. Gole, T. Nalange, and P. Gaikwad, "Consumers Perception towards Hydroponically Grown Residue-Free Vegetables," (2020), *Our Herit.*, vol. 68, no. 30, pp. 8215–8229.