Vol. 13, No. 4, pp. 1163-1170, November 2025 DOI:https://doi.org/10.23960/jat.v13i4.10465

JurnalAgrotekTropika

P-ISSN:2337-4993
E-ISSN:2620-3138

Journal homepage:https://jurnal.fp.unila.ac.id/index.php/JA

EVALUASI KONSENTRASI NUTRISI TERHADAP PERTUMBUHAN SAWI PAKCOY (*Brassica rapa* L.) MENGGUNAKAN HIDROPONIK NFT (NUTRIENT FILM TECHNIQUE) BERSENSOR

EFFECT OF NUTRIENT SOLUTION CONCENTRATION ON THE GROWTH PERFORMANCE OF PAKCOY MUSTARD (Brassica rapa L.*) UNDER A SENSOR-BASED NUTRIENT FILM TECHNIQUE HYDROPONIC SYSTEM*

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ARTICLE HISTORY:
Received: 3 March 2025
Peer Review: 11 July 2025
Accepted: 30 October 2025

KATA KUNCI:
Konduktivitas listrik

ABSTRAK

Pertumbuhan tanaman sawi pakcoy dapat dipengaruhi oleh konsentrasi dan komposisi larutan nutrisi hidroponik. Tujuan dari penelitian ini adalah untuk mengidentifikasi konsentrasi larutan nutrisi yang ideal untuk pertumbuhan sawi pakcoy saat panen. Pengaturan eksperimen yang diadopsi adalah desain blok acak dengan 5 level konduktivitas listrik (KL) yang berbeda, yaitu 0,8 mS.cm^{-1}, 1,2 mS.cm^{-1}, 1,6 mS.cm^{-1}, 2,0 mS.cm^{-1}, dan 2,4 mS.cm^{-1}, dengan sepuluh ulangan untuk setiap perlakuan. Parameter yang dievaluasi untuk menilai efektivitas masing-masing perlakuan meliputi tinggi tanaman, jumlah daun, luas daun, berat segar keseluruhan tanaman, dan tingkat klorofil. Data dianalisis menggunakan Duncan Multiple Range Test (DMRT) ($p < 0,05$) untuk mengidentifikasi perbedaan di antara perlakuan. Temuan menunjukkan bahwa EC 2,0 mS.cm^{-1} menghasilkan pertumbuhan tertinggi sawi pakcoy, dengan tinggi tanaman mencapai 9,6±2,38 cm, jumlah daun 23,9±2,13, luas daun 32,81±8,95 cm^2, dan konsentrasi klorofil 5,9±0,52 mg.l^{-1} pada umur panen 4 minggu.

KEYWORDS:
Electrical conductivity

ABSTRACT

The growth of pakcoy mustard (Brassica rapa L.) is strongly influenced by the concentration and composition of hydroponic nutrient solutions. This study aims to determine the optimal nutrient solution concentration for maximized pakcoy mustard growth at harvest. The experimental setup adopted was a randomized block design featuring 5 different levels of electrical conductivity (EC), specifically 0.8 mS.cm^{-1}, 1.2 mS.cm^{-1}, 1.6 mS.cm^{-1}, 2.0 mS.cm^{-1}, and 2.4 mS.cm^{-1}, with replicated ten times. The parameters evaluated to assess the efficacy of each treatment include plant height, number of leaves, leaf area, overall fresh weight of the plant, and chlorophyll levels. Data were analyzed using Duncan Multiple Range Test (DMRT) at a 5% significance level($p < 0.05$). The results indicated that an EC of 2.0 mS.cm^{-1} led to the greatest growth of pakcoy mustard, achieving a plant height of 9.6±2.38 cm, a leaf count of 23.9±2.13, a leaf area of 32.81±8.95 cm^2, and a chlorophyll concentration of 5.9±0.52 mg.l^{-1}with a harvest period of four weeks.

1. INTRODUCTION

Pakcoy mustard (*Brassica rapa* L.) is a leafy vegetable belonging to the mustard family. it is considered an economically valuable crop and provides numerous health advantages. Pakcoy mustard is high in minerals and vitamins (including vitamins K, A, C, and E), as well as folic acid. The increasing demand for vegetable consumption among the Indonesian population must be matched by higher production levels. Therefore, to enhance the yield of vegetable crops such as pakcoy, hydroponic methods have been widely adopted. Vegetables are particularly suited for hydroponic methods since they have relatively small and light stems (Rosman *et al*., 2019). Furthermore, the reduction of agricultural land due to the conversion of agricultural land to non-agricultural areas has encouraged the agricultural sector, both the government and farmers, to increase crop production in a restricted area. Consequently, the adoption of hydroponic farming systems provides an effective solution to this issue (Sardare and Admane, 2013; Barbosa *et al*., 2015; Khan *et al*., 2018; Rajaseger *et al*., 2023).

The hydroponic farming method involves growing plants without soil, instead relying on nutrient solutions to promote plant development (Fuzzy and Papenbrock, 2022). The Commercial Nutrient Film Technique (NFT) hydroponic system has been utilized globally, resulting in high yields of leafy vegetables and other crops while conserving 70% to 90% less water (Sharma *et al*., 2019). NFT is a hydroponic system in which the nutrient solution continuously circulates. Plant nutrient requirements are supplied in the form of inorganic nutrient solutions consisting of dissolved macronutrient and micronutrient salts commonly prepared in nutrient stock solutions A and B.

Meeting the optimal nutrient requirements is a crucial factor in cultivating *Brassica oleracea*e L. (Sinaga *et al*., 2014), mustard greens (Pakpahan *et al*., 2020), sweetpotato (Sakamoto and Suzuki, 2020) under hydroponic conditions. The nutrient levels in the solution were determined based on electrical conductivity (EC) measurements. Electrical conductivity indicates the total concentration of dissolved ions in the solution, reflecting its overall nutrient strength. Enhancing the nutrient availability can therefore increase yield and overall productivity. In conventional soil-based cultivation, pakcoy mustard typically requires approximately ± 45 days to reach harvest maturity. Nevertheless, hydroponic cultivation is expected to be quicker, requiring only about four weeks to achieve the equal biomass to those traditional grown plants. This study aims to determine the optimal nutrient solution concentration for mustard greens growth in a sensor-driven hydroponic NFT system within a four-week cultivation period.

2. MATERIALS AND METHODS

This study was conducted from October to November 2024 in the greenhouse of the University of Surabaya, Indonesia. The study site is located at an altitude of approximately 50 meters above sea level (m asl). The instruments and materials used in this research included an EC-meter, pH-meter, hygrometer, aerator, water pump, leaf area meter, digital scale, pakcoy mustard seeds, rockwool growing medium, AB Mix nutrient solutions, and a NFT hydroponic system equipped with sensors to monitor nutrient electrical conductivity (EC), solution pH, and relative humidity (RH).

The experiment was arranged in a randomized block (RBD) consisting of five treatments, with different electrical conductivity (EC) levels: 0.8, 1.2, 1.6, 2.0, and 2.4 $mS.cm^{-1}$. Each treatment was replicated ten times. The pH of the nutrient solution was maintained at a constant value of 6.0 throughout the experiment. During the initial week, seedlings were supplied with a nutrient solution at an EC of 0.5 $mS.cm^{-1}$, followed by the application of the five EC treatments described earlier in the subsequent weeks.

Non-destructive observations were conducted weekly to assess plant height, leaf number, leaf area, total fresh weight, total dry weight, and chlorophyll content were measured at 4 weeks after transplanting. Data were analyzed using Analysis of Variance (ANOVA) at a significance level of α = 0.05 and followed by the Duncan Multiple Range Test (DMRT) to determine significance differents among treatments. Harvesting was carried out in the fourth week after transplanting to the hydroponics system.

Shoot and root samples were oven-dried at 85°C for 48 hours. The root/shoot ratio was calculated by dividing the root dry weight by the shoot dry weight (Li *et al*., 2018). Chlorophyll content was conducted from the largest leaves. Approximately 0.3 g of the leaves were ground in a mortar under cryogenic conditions using liquid nitrogen (N_2) until a fine powder was obtained. The fine powder was placed in a falcon tube and mixed with 5 mL of acetone, then incubated for 24 hours. The extract was centrifuged, and the supernatant was collected for absorbance measurement using a spectrophotometer at wavelengths of 645 nm and 663 nm. Chlorophyll a = $12.72*A_{663}-2.59*A_{645}$; Chlorophyll b = $22.9*A_{645}-4.67*A_{663}$; Total chlorophyll = $20.31*A_{645}+8.05*A_{663}$ (Sukweenadhi *et al*., 2018).

3. RESULT AND DISCUSSION

The average height of pakcoy mustard at various concentrations of nutrient solution during 4 weeks is shown at Figure 1. Based on Figure 1, an electrical conductivity (EC) of 2.0 mS.cm^{-1} resultied in the tallest average plant height of pakcoy mustard, reaching approximately 9.6 cm after four weeks of growth. Increasing EC levels generally promotes vegetative growth (figure 1), which is consistent with the findings of Del Carmen Salas *et al*., (2020) who reported that an EC of 3.0 dS.m^{-1} was ideal for saffron growth and corm yield compared to lower EC levels such as 2.0 dS.cm^{-1} and 2.5 dS.cm^{-1}. Conversely, Dewir and Alsadon (2022) state that the lowest EC level in their study enhance the vegetative growth of saffron, as the roots were continuously submerged in the nutrient solution. Similarly Pratiwi *et al*., (2015) found that the ideal EC level for the fresh weight of mustard was 2.5 mS.cm^{-1} produced the highest fresh weight in mustard plants. These findings indicate that EC levels substantially influence the vegetative growth performance of pak choy mustard during the four-week growth period.

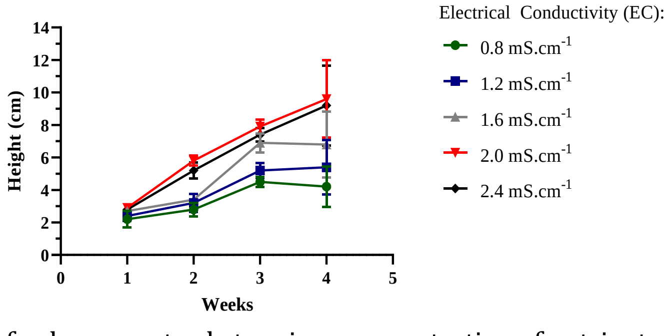


Figure 1. Average height of pakcoy mustard at various concentration of nutrient solution during 4 weeks

Table 1. Average plant height, number of leaves, and leaf area at various nutrient solution concentrations for 4 weeks.

Value of EC (mS.cm^{-1})	Plant height (cm)	Number of leaves	Leaf area (cm^2)
0.8	4.2±1.25^a	16.4±1.85^a	28,96±2,89^a
1.2	5.4±1.67^a	17.7±1.57^a	29,05±5,48^a
1.6	6.8±2.05^b	19.6±2.89^b	31,15±7,86^b
2.0	9.6±2.38^c	23.9±2.13^c	32,81±8,95^c
2.4	9.2±2.46^c	23.2±2.46^c	32,00±2,42^c

Note(s): values followed by the same letter in the same column were not significantly different at $p < 0.05$ by DMRT.

Figure 2. Hydroponic pakcoy mustard ready to harvest (4 weeks)

Nevertheless, the optimal EC level varies among plants spesies and is influenced by several factors such as growth stage, species, season, and water quality (Sangeetha and Periyathambi, 2024). Determining the appropriate EC level for plant growth is essential, as an excessively high EC level can hinder nutrient absorption (Hosseini *et al*., 2021) by increasing the osmotic potential of the nutrient solution. Conversely, an EC level that is too low may induce nutrient deficiency stress, thereby reducing plant growth and overall quality (Ding *et al*., 2018). In general, elevated EC levels can enhance vegetative growth, particularly plant height, by improving nitrogen availability and promoting its role in stems and leaf development (Tripama and Yahya, 2018). Average plant height, number of leaves, and leaf area at various nutrient solution concentrations for 4 weeks can be shown at Table 1 and Figure 2.

Based on Table 1, the highest number and leaf area of pakcoy were observed at an EC value of 2.0 mS.cm^{-1}, with 23.9±2.13 leaves and a total leaf area of 32.81±8.95, respectively. The EC value influences plant metabolism by affecting the rate of photosynthesis, enzyme activity, and the efficiency of ion uptake through the roots (Pratiwi *et al*., 2015; Nafiah *et al*., 2023). Both the number and area of leaves increased with rising EC value, reaching their maximum at 2.0 mS.cm^{-1}, before declining at higher EC values. The reduction in leaf number and size under excessive EC conditions may be attributed to osmotic stress or ion toxicity resulting from the high concentration of dissolved salts (Albornoz & Lieth, 2015). Similarly, Ding *et al*., (2018) reported enhanced growth at EC levels of 1.8 dS.m^{-1} and above. Leaf area is closely related to photosynthesis performance, where larger leaves enhance light interception and photosynthetic efficiency, thereby supporting optimal growth (Rosman *et al*., 2019). Consequently, the tallest and heaviest plants were observed at an EC value of 2.0 mS.cm^{-1}. Additionally, the increase in nitrate accumulation observed at higher EC levels was a physiological response to elevated nutrient concentration in the solution (Fallovo *et al*., 2009). Since nitrate plays a key role in plant growth and metabolism, determining the optimal EC value is essential to maximize nutrient absorption while avoiding toxic and inhibitory effects on plant development.

Based on Table 2, the highest root-to-shoot ratio of pakcoy mustard (4.8 ± 18.95) was specifically observed in the EC treatment at 2.0 mS.cm^{-1}. This indicates that the translocation of photosynthates was more concentrated in the shoot than in the root system, resulting in enhanced vegetative shoot growth and relatively limited carbohydrate allocation to the roots. The EC value of the nutrient solution directly affects nutrient availability within the root zone, thereby influencing nutrient uptake, root development, and overall plant productivity (Chang *et al*., 2011).

The maximum total fresh weight observed at an EC level 2.0 mS.cm^{-1} can be attributed to optimal nutrient availability throughout the growth stage, which promotes higher biomass fresh weight (Embarsari *et al*., 2015). Additionally, the fresh weight of plants is strongly influenced by the leaf number and leaf area, as increase in both parameters enhances the plant's photosynthetic capacity and consequently elevates fresh weight (Stefanov *et al*., 2016). Subsequently, the greater fresh weight results in the higher total dry weight, reflecting improved plant growth performance under the optimal EC treatment.

Table 2. Average total fresh weight, shoot fresh weight, and shoot/root ratio at various nutrient solution concentrations for 4 weeks.

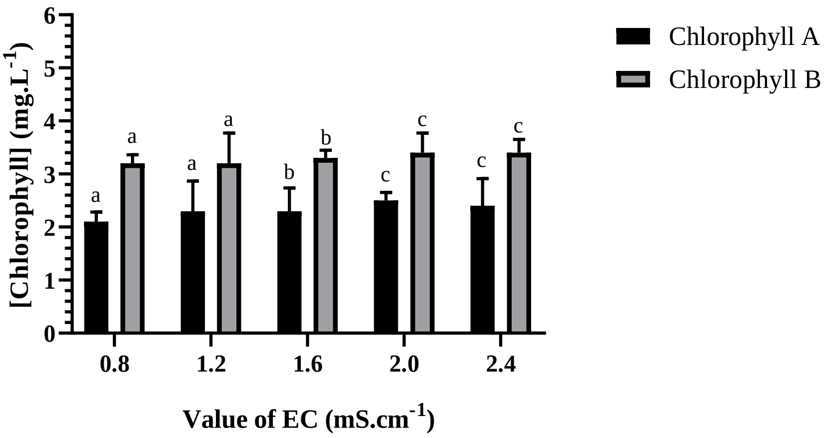
Value of EC ($mS.cm^{-1}$)	Total fresh weight (g)	Total oven dry weight (g)	Root/shoot ratio
0.8	158.8±2.45[a]	6.7±2.46[a]	2.9±12.89[a]
1.2	165.9±2.75[a]	7.5±3.57[a]	3.1±15.48[a]
1.6	195.7±2.49[b]	8.6±2.95[b]	3.5±17.86[a]
2.0	210.5±2.79[c]	10.3±2.45[c]	4.8±18.95[b]
2.4	211.3±2.93[c]	9.1±2.78[c]	4.9±20.42[b]

Note(s) : values followed by the same letter in the same column were not significantly different at p < 0.05 by DMRT.

Table 3. Correlation between the variation of EC to growth parameter.

Variable X		Variable Y			
EC Value		Plant Height (cm)	Number of Leaves	Leaf Area (cm^2)	Fresh Weight (g)
	P value	0,0108	0,0146	0,0394	0,0110
	R^2	0,9152	0,8965	0,8035	0,9140

Note(s): P value < 0.05 was significantly correlated between two variables (X and Y) which analysis using pearson correlation (α < 0.05).



Note(s): bar followed by the same letter in the same chlorophyll types were not significantly different at p < 0.05 by DMRT.

Figure 3. Average Chlorophyll a and b at various nutrient solution concentrations for 4 weeks.

Average Chlorophyll a and b at various nutrient solution concentrations for 4 weeks are shown at Figure 3. According to Figure 3, the highest chlorophyll content was observed at EC values of 2.0 $mS.cm^{-1}$ and 2.4 $mS.cm^{-1}$. Similar to the findings of Ding *et al.*, (2018) both excessively low and high EC levels can greatly reduce the photosynthesis process. Variation in EC influences photosynthetic rates primarily through the availability of essential elements, such as nitrogen (N), magnesium (Mg), and iron (Fe), which are essential for chlorophyll biosynthesis. Consequently, the deficiency of these elements resulted in a decline in chlorophyll content.

Furthermore, under salinity stress conditions, chlorophyll concentration may increase as a physiological response to enhance salt tolerance, since elevated EC levels can induce osmotic or salinity stress (Stefanov *et al.*, 2016). Thus, higher chlorophyll accumulation under moderate EC stress might reflect an adaptive mechanism rather than an indicator of improved photosynthetic performance. Chlorophyll content strongly correlates with photosynthetic capacity, and higher photosynthetic activity generally supports improved vegetative growth.

The correlation between EC variation and several growth parameters, including plant height, leaf number, leaf area, fresh weight, and dry weight, is presented in Table 3. As presented in Table 3, several growth parameters exhibited significant correlation with the EC value ($p < 0.05$). The positive correlation coefficients indicate that increasing EC levels were associated with higher values of plant height, leaf number, leaf area, and fresh weight. These results suggest that a moderate increase in EC enhances vegetative growth by improving nutrient availability and uptake efficiency. However, excessively high EC values may adversely affect plant growth due to osmotic stress or ion toxicity, thus emphasizing the importance of determining the optimal EC range for hydroponic cultivation (Hoang et al., 2019; Desmasari dkk., 2022; Sun et al., 2023; Vought et al., 2024). The overall influence of EC on the observed growth parameters has been consistently demonstrated in the preceding sections.

4. CONCLUSION

This study concludes that an electrical conductivity (EC) of 2.0 mS·cm^{-1} represents the optimal nutrient concentration for pakcoy mustard grown hydroponically, resulting in superior vegetative growth, biomass accumulation, and a shortened cultivation period of four weeks.

5. ACKNOWLEDMENTS

This study is supported by grants Empowerment Program Community Based (Program Berbasis Masyarakat) with the scope of Community Partnership Empowerment from the Directorate of Research, Technology and Community Service (DRTPM) Ministry of Education, Culture, Research and Technology with the contract number of 017/SPP-PPM/LPPM-02/Dikbudristek/FTB/VI/ 2024 31st July 2024 (on behalf of Dr. Ir. Popy Hartatie Hardjo, M.Si.).

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