ASEAN
Journal of Scientific and Technological Reports
Online ISSN:2773-8752

Research article

Effects of Hydroponic Cultivation Systems on Growth Performance and Yield of Pakchoi (*Brassica rapa* var. *chinensis*)

Pakamas Thaenkaew[1], Ronnarit Khuengphukhiao[1*], Sirawat Surachotivet[1], and Khitaphat Khongthaen[1]

[1] Faculty of Engineering, Pathumwan Institute of Technology, Bangkok, 10330, Thailand
* Correspondence: ronna_rit@hotmail.com

Citation:
Thaenkaew, P.; Khuengphukhiao, R.; Surachotivet, S.; Khongthaen K. Effects of hydroponic cultivation systems on growth performance and yield of pakchoi (*Brassica rapa* var. *chinensis*). *ASEAN J. Sci. Tech. Report.* **2026**, *29*(4), e261311. https://doi.org/10.55164/ajstr.v29i4.261311.

Article history:
Received: September 16, 2025
Revised: February 19, 2026
Accepted: March 10, 2026
Available online: March 25, 2026

Abstract: The purpose of this study was to investigate the effects of different hydroponic systems on the growth and yield of Pakchoi (*Brassica rapa* var. *chinensis*). The experiment was conducted using a Randomized Complete Block Design (RCBD) to compare three hydroponic cultivation systems: (1) Deep Flow Technique (DFT), (2) Nutrient Film Technique (NFT), and (3) Drip Hydroponics System (DHS). Each treatment consisted of 10 individual plants, yielding a total of 30 experimental units. Plants were cultivated for 35 days after transplanting under controlled laboratory conditions. The nutrient solution was maintained at a pH range of 5.5–6.5 and an electrical conductivity (EC) of 1.5–2.5 mS cm^{-1}. Environmental parameters were carefully regulated, including temperature (20–25 °C), relative humidity (60–70%), and light intensity (200–250 µmol m^{-2} s^{-1}), under a 16 h light/8 h dark photoperiod. The results indicated that the cultivation system had a statistically significant effect ($p < 0.05$) on plant height, leaf width, and fresh weight yield. Pakchoi grown under the DHS treatment exhibited superior growth performance, with an average plant height of 41.71 cm, leaf width of 14.67 cm, and fresh weight yield of 64.8 g, all of which were higher than those observed in the NFT and DFT systems. In addition, qualitative observations revealed improved leaf expansion and greater canopy development under the DHS treatment. These findings demonstrate that the Drip Hydroponics System is an effective cultivation approach for enhancing Pakchoi growth and yield under controlled-environment conditions.

Keywords: Hydroponics; pakchoi; growth performance; yield; drip hydroponics

1. Introduction

Hydroponic cultivation is an agricultural technology that replaces soil with nutrient solutions for crop production [1]. This approach minimizes soil-borne diseases, reduces land requirements, and has been widely adopted in both commercial and research contexts [2]. Nevertheless, hydroponic systems require precise management of fertilizer application and close monitoring of environmental parameters, particularly pH and electrical conductivity (EC), which directly influence nutrient uptake and plant growth. Proper regulation of these factors can significantly enhance crop performance and yield. Recent advances in hydroponic technology have focused on improving production efficiency through automation and sustainable practices. For instance, automated irrigation and fertigation systems have been widely implemented in vertical farming operations [3]. In addition, the integration of organic fertilizers and beneficial microorganisms has been explored to reduce reliance on chemical inputs and enhance system sustainability [4–5]. Complementary technologies, such as LED lighting, have been adopted to stabilize light conditions, improve photosynthetic efficiency, and enhance crop quality, thereby reducing dependence on fluctuating natural sunlight [6]. Furthermore, non-thermal plasma treatments have been introduced to mitigate salinity stress [7], while biological agents, including chitosan nanoparticles, have been investigated to improve sustainability and plant resilience in hydroponic systems [8].

Several hydroponic systems are commonly employed in commercial production. The drip irrigation system (DIS) is recognized for its ability to conserve water and improve yield quality [9]. The nutrient film technique (NFT), also known as the thin-film system, is particularly suitable for small, fast-growing plants due to its efficient nutrient delivery [10]. In contrast, the deep flow technique (DFT) provides greater root-zone volume and stability, making it more suitable for supporting larger plants and achieving higher yields [11]. Each of these systems offers distinct advantages and limitations in terms of resource efficiency, crop compatibility, and commercial applicability. Commercial growers widely favor Pakchoi because it reaches maturity in 30–35 days, requires relatively low nutrient levels, and yields high per-unit-area. These characteristics make Pakchoi an ideal crop for hydroponic cultivation, particularly in urban farming, greenhouse production, and vertical farming systems where land and water use efficiency are critical. Selecting an appropriate hydroponic system is therefore essential for maximizing yield and product quality while ensuring economically and environmentally sustainable production. Although several studies have investigated the hydroponic cultivation of Brassica crops, few have specifically focused on Pakchoi. Therefore, the objective of this study was to compare the growth and yield performance of Pakchoi cultivated under three hydroponic systems: DFT, NFT, and DIS. Growth parameters, including plant height and leaf width, as well as fresh weight yield, were evaluated and subjected to statistical analysis to determine the most suitable system for commercial Pakchoi production.

2. Materials and Methods

The experiment was conducted in a hydroponic cultivation unit measuring 0.85 × 1.20 × 1.20 meters. Environmental parameters were controlled using artificial lighting, including LED white light and a night light, while maintaining the room temperature between 20 and 25 °C. The nutrient solution applied for cultivating Pakchoi was adjusted to a pH range of 5.5–6.5 and an electrical conductivity (EC) range of 1.5–2.5 mS/cm. The experiment was arranged in a Randomized Complete Block Design (RCBD) with three hydroponic cultivation systems: Deep Flow Technique (DFT), Nutrient Film Technique (NFT), and Drip Hydroponics System (DHS). Each treatment comprised 10 individual Pakchoi plants, yielding a total of 30 experimental units. Each plant was considered as one replicate for statistical analysis. Three hydroponic systems were evaluated:

1. Static Hydroponics (Deep Flow Technique, DFT) This system consisted of a tank filled with nutrient solution in which the plant roots were immersed. The solution was not continuously circulated; however, aeration was provided through an air stone to increase dissolved oxygen levels.

2. Nutrient Film Technique (NFT): Plant roots were continuously supplied with a thin film of nutrient solution combined with oxygen from the surrounding air.

3. Drip Hydroponics System: Nutrient solution was delivered directly to the root zone in pulses or at predetermined intervals. This method enabled precise regulation of nutrient supply and timing, thereby reducing water consumption.

Pakchoi seedlings were germinated for 14 days before transplantation. After transplanting, plants were grown under hydroponic conditions for 35 days, corresponding to the typical commercial harvest period for Pakchoi. Final harvest and yield measurements were conducted at the end of the cultivation period (Day 35 after transplanting). During the early stage of transplantation, plain water was used in the troughs without nutrient supplementation, and water pH was monitored. From the first day after transplantation, the solution was replaced with a nutrient medium maintained at pH 5.5–6.5 and EC 1.5–2.5 mS/cm throughout the growing cycle. Environmental conditions were maintained under controlled indoor conditions throughout the experiment. The cultivation room temperature was maintained at 20–25 °C, relative humidity ranged between 60–70%, and light was supplied using white LED lamps with an average light intensity of approximately 200–250 μmol m^{-2} s^{-1} at canopy level under a 16 h light / 8 h dark photoperiod. These environmental conditions were kept constant across all treatments to minimize external factors that could affect plant growth. Growth performance was assessed by measuring plant height, defined as the distance from the base of the stem to the tip of the tallest leaf. Measurements were taken at 7-day intervals from the time of transplantation until harvest. Leaf width was determined by measuring the broadest point of the most fully developed leaf on each plant, conducted concurrently with height measurements. Growth rate for both height and leaf width was calculated according to Equation (1), where X_0 = initial value and X_t = Value at time t. Fresh biomass was recorded in grams (g) using a digital scale. The collected data were subjected to analysis of variance (ANOVA) to identify significant differences in growth and yield across the hydroponic systems, using Design-Expert 7.0 statistical software.

$$\text{Growth Rate (\%)} = (X_t - X_0) / X_0 \times 100 \quad (1)$$

Figure 1. Operational Procedure Diagram

3. Results and Discussion

In the experiment, Pakchoi was cultivated using three hydroponic systems: a stagnant-water system (Deep Flow Technique, DFT), a whirlpool system (Nutrient Film Technique, NFT), and a drip irrigation system (Drip Hydroponics System, DHS). Data were collected for plant height, leaf width, plant height growth rate, leaf width growth rate, and yield, as presented in Figures 2(a)–4(a). These figures illustrate the normality tests for plant height growth rate, leaf width growth rate, and yield. Figures 2(b)–4(b) present the constant variance tests, showing the relationship between stochastic tolerance and predicted values, which indicate no correlation between stochastic deviation and predicted values. Figures 2(c)–4(c) illustrate the relationship between stochastic tolerance and the data sequence, while Figure 4(d) shows the relationship between observed experimental values and predicted values. The close agreement between observed and predicted results confirms that the statistical models applied were appropriate for predicting experimental outcomes. Furthermore, the absence of heteroscedasticity indicates that plant height growth rate, leaf width growth rate, and yield data were suitable for analysis of variance without the need for data transformation. In addition to quantitative measurements of plant height, leaf width, and fresh weight, visual observations revealed that plants grown under the DHS treatment had more fully expanded leaves and greater canopy coverage than those grown under DFT and NFT systems. The enhanced growth performance observed under DHS can be attributed to precise nutrient delivery, reduced root-zone waterlogging, and improved oxygen availability. Although production costs were not quantitatively evaluated in this study, DHS is expected to require a higher initial investment; however, it may provide long-term benefits through improved yield efficiency and reduced water and nutrient losses.

The adequacy analysis of the statistical models (Figures 2–4) confirms that the experimental data were sufficiently robust for evaluating the effects of the hydroponic systems. Consequently, the data were analyzed using analysis of variance (ANOVA). The model for plant height yielded an F-value of 121.86 and a p-value < 0.0001, indicating that the hydroponic systems (DFT, NFT, and DHS) had a statistically significant effect on plant height ($p < 0.05$). The goodness-of-fit statistics yielded $R^2 = 0.90$, Adjusted $R^2 = 0.89$, and Predicted $R^2 = 0.87$, consistent with Figure 5(a). The results demonstrate that the drip irrigation system achieved the highest average plant height, with mean values of 30.49 cm (DFT), 37.11 cm (NFT), and 41.71 cm (DHS). Compared with DFT and NFT, the DHS system increased plant height by 26.90% and 11.03%, respectively. For leaf width growth rate, the statistical model yielded an F-value of 67.61 and a p-value < 0.0001, confirming significant differences among the hydroponic systems ($p < 0.05$). The model fit parameters were $R^2 = 0.83$, Adjusted $R^2 = 0.82$, and Predicted $R^2 = 0.79$, as shown in Figure 5(b). At weeks 1 and 5, the drip irrigation system produced the highest average leaf width (14.67 cm), followed by NFT (11.87 cm) and DFT (9.42 cm). The DHS system outperformed DFT and NFT by 35.76% and 19.09%, respectively. These findings are consistent with those reported by [12], who indicated that commonly used hydroponic systems exhibit distinct characteristics that differentially influence plant growth. Regarding yield, the model yielded an F-value of 242.2 ($p < 0.0001$), indicating that hydroponic systems had a statistically significant effect on yield ($p < 0.05$). The model fit values were $R^2 = 0.94$, Adjusted $R^2 = 0.94$, and Predicted $R^2 = 0.93$, corresponding to Figure 5(c). The highest average yield was obtained under the drip irrigation system (64.8 g), followed by NFT (44.5 g) and DFT (26.9 g). Overall, DHS outperformed DFT and NFT by 58.49% and 31.33%, respectively. These results are consistent with previous studies reporting that effective water circulation enhances plant growth [13] and that irrigation regimes significantly influence crop growth and yield [14]. Although quantitative assessments in this study focused on plant height, leaf width, and fresh weight, qualitative observations throughout the cultivation period revealed clear differences in plant architecture among the hydroponic systems. Plants grown under the DHS treatment consistently exhibited a greater number of fully expanded leaves and a more extensive canopy than those grown under DFT and NFT systems. This enhanced leaf development suggests an increased photosynthetic surface area, which likely contributed to the significantly greater biomass accumulation observed at harvest. Furthermore, weekly growth monitoring revealed more stable, uniform growth patterns in DHS-grown plants, whereas plants cultivated under DFT and NFT systems exhibited slower, less consistent development during the early growth stages. These qualitative and temporal growth patterns support the quantitative findings and suggest that incorporating additional growth indicators—such as leaf number, leaf area index, and daily growth rate—could provide more comprehensive insights into system performance in future studies.

Leafy vegetables are generally reported to grow rapidly in liquid-based hydroponic systems, including NFT, deep-water culture (DWC), ebb-and-flow, and aeroponics, as plant roots receive a continuous supply of nutrients in oxygenated aqueous environments [15]. In NFT systems, oxygen availability is partially maintained by exposing root tips to air; however, this configuration may result in uneven nutrient distribution and increased sensitivity to flow interruptions. In DWC systems, adequate root oxygenation relies heavily on supplemental aeration, and insufficient dissolved oxygen levels may induce hypoxic stress unless additional aeration is provided [16,17]. The superior growth performance and yield observed in the Drip Hydroponics System (DHS) are attributable to a combination of physiological and system-level advantages. DHS enables precise and uniform delivery of nutrient solution directly to the root zone, ensuring consistent nutrient availability throughout the cultivation cycle. In addition, intermittent nutrient solution application minimizes prolonged root submergence, thereby improving root-zone aeration and oxygen diffusion compared with DFT systems. This optimized balance of water, nutrients, and oxygen promotes efficient nutrient uptake, enhanced root development, and increased photosynthetic efficiency, ultimately resulting in greater biomass accumulation and yield. The statistically significant differences observed among hydroponic systems further support these conclusions. Overall, the findings align with previous studies demonstrating that drip-based hydroponic systems improve water-use efficiency, stabilize growth rates, and enhance crop productivity relative to static or continuous-flow hydroponic systems.

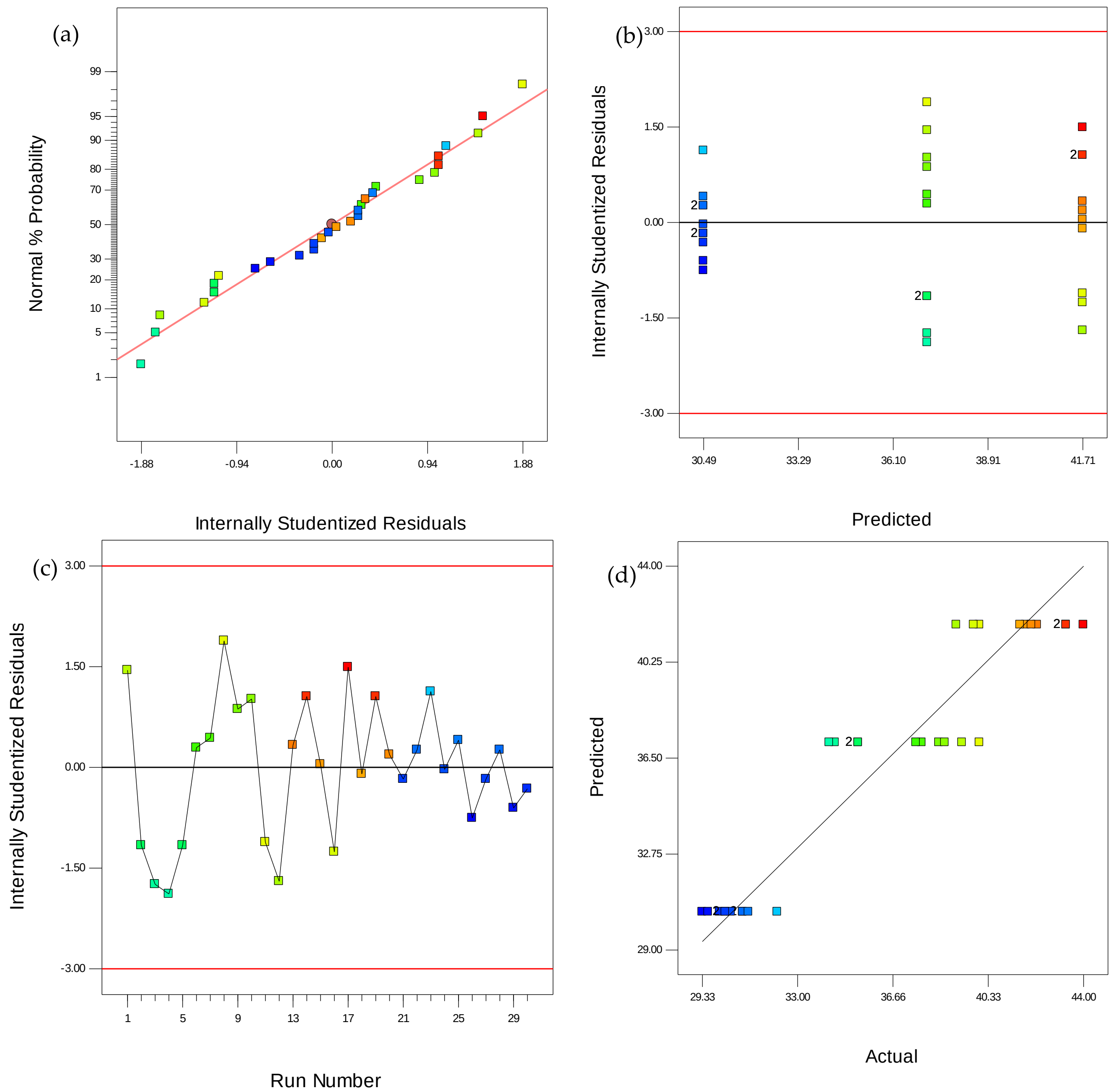

Figure 2. Diagram of the random tolerance of the growth rate of the early height (a) Normal distribution test of the data, (b) Constant variance test, (c) Graph of the relationship between random and ordinal tolerances, and (d) Graph of the relationship between the actual experimental results and the predicted values.

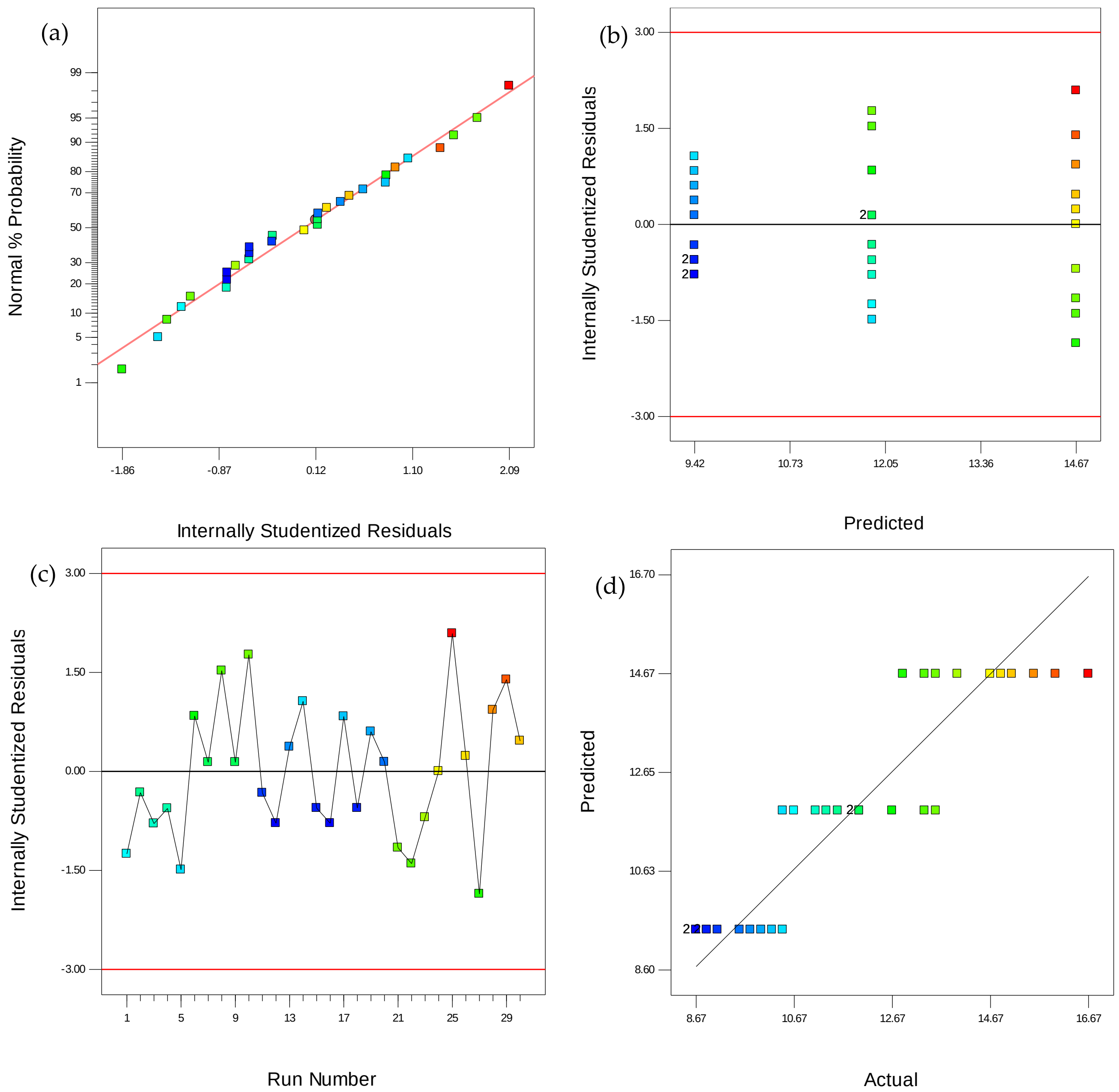

Figure 3. Random tolerance diagram of leaf width growth rate (a) Normal distribution test of data, (b) constant variance test, (c) Graph of the relationship between random and ordinal tolerances, and (d) graph of the relationship between actual experimental results and predicted values.

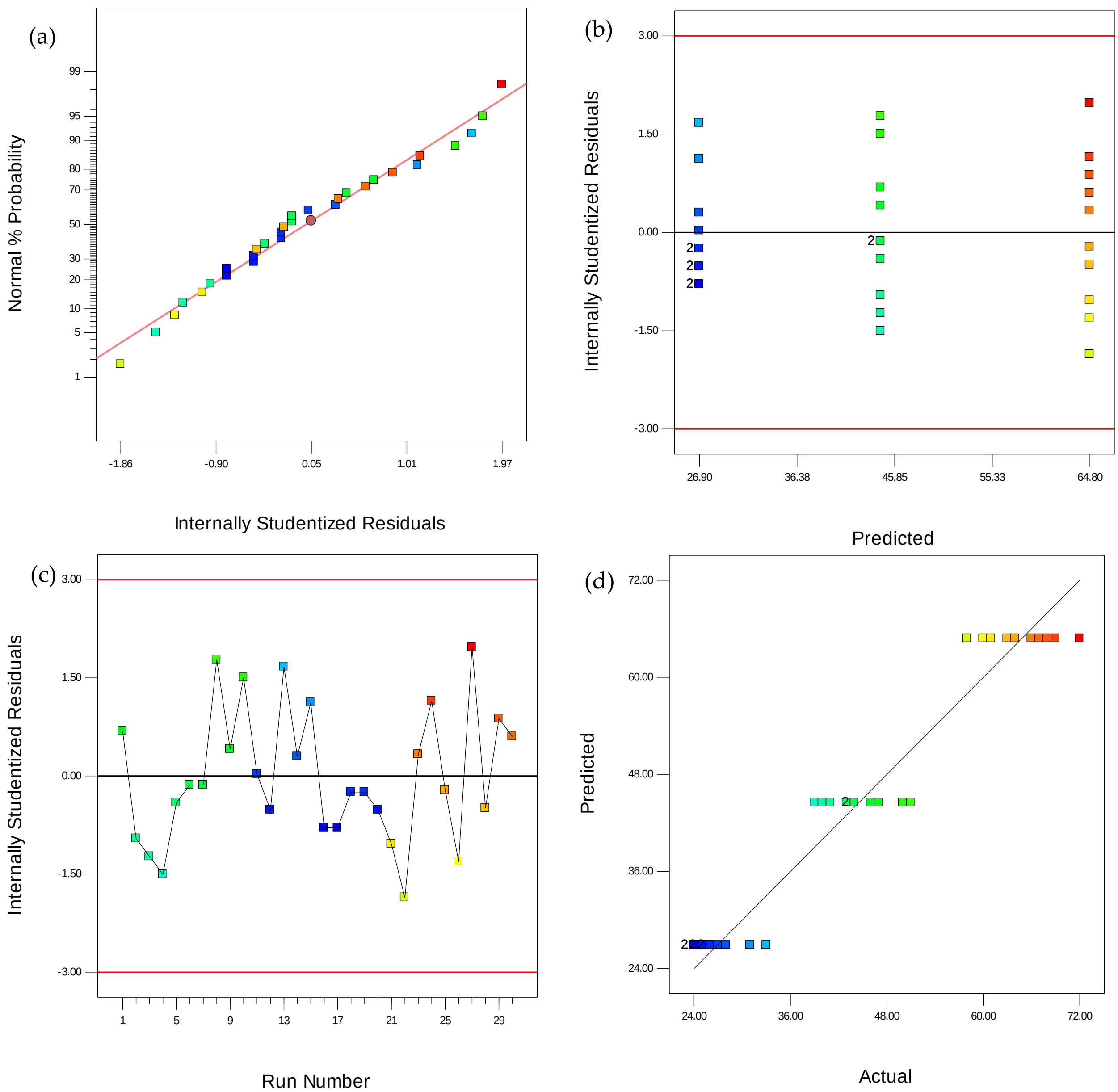

Figure 4. Output random tolerance diagram (a) Normal distribution test of data, (b) Constant variance test, (c) Graph of the relationship between random and ordinal tolerances, and (d) Graph of the relationship between actual experimental results and predicted values.

4. Conclusions

This study compared three hydroponic cultivation systems—Deep Flow Technique (DFT), Nutrient Film Technique (NFT), and Drip Hydroponics System (DHS)—to evaluate their effects on Pakchoi (Brassica rapa var. chinensis) growth and yield. Growth performance was assessed based on plant height, leaf width, and the growth rates of these traits, while yield was evaluated as fresh weight. The results demonstrated that the Drip Hydroponics System (DHS) consistently outperformed the other two systems in promoting plant height and leaf expansion. Although all three hydroponic systems influenced Pakchoi growth and productivity, DHS was particularly effective in enhancing early vegetative growth and overall yield compared with DFT and NFT. Regarding leaf width, average values of 9.42 cm, 11.87 cm, and 14.67 cm were recorded under DFT, NFT, and DHS, respectively, indicating superior leaf development under drip irrigation. Yield analysis further confirmed the advantages of DHS. The mean fresh weights were 26.9 g for DFT, 44.5 g for NFT, and 64.8 g for DHS. Accordingly, the drip irrigation system produced yields that were

58.49% higher than those obtained with DFT and 31.33% higher than those achieved with NFT. Overall, these findings indicate that the Drip Hydroponics System is the most suitable method for the commercial cultivation of Pakchoi, as it delivers higher yields, promotes stronger vegetative growth, and allows more effective control of crop quality compared with stagnant water and whirlpool hydroponic systems.

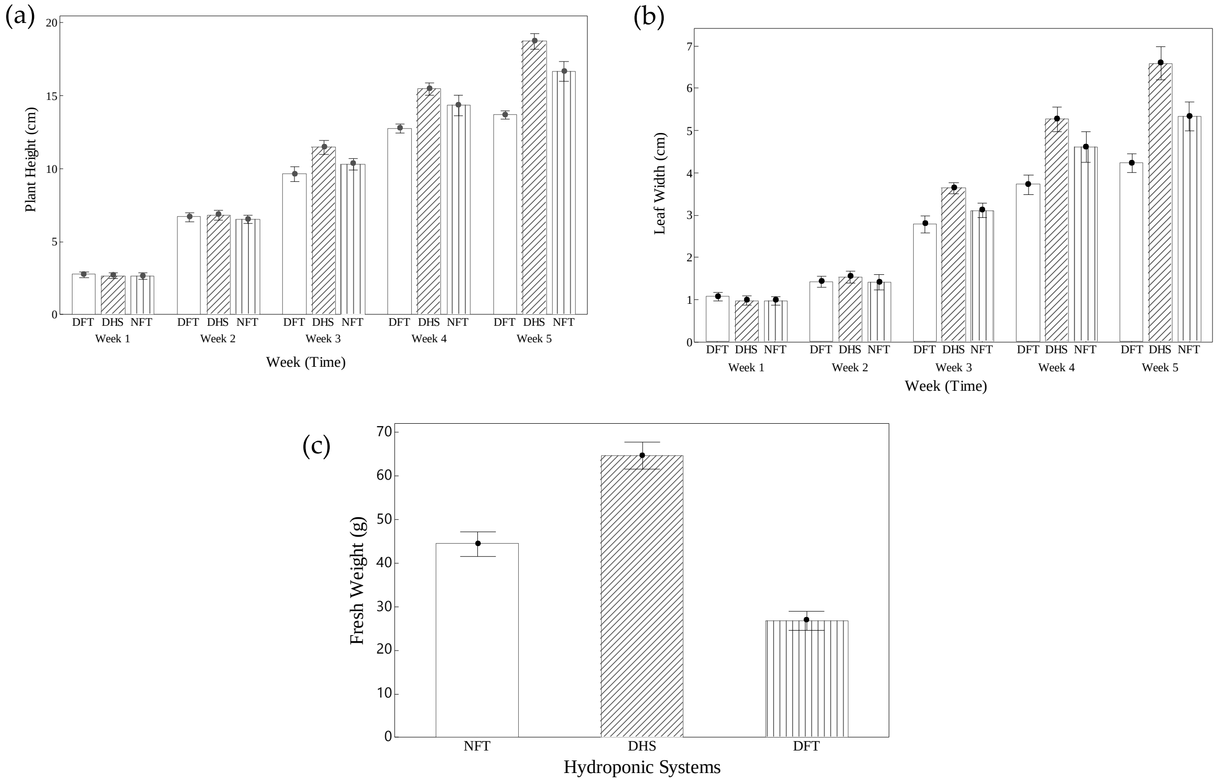

Figure 5. Cantonese planting system diagram with hydroponics (a) Plant height, (b) leaf width, and (c) Cantonese vegetable yield.

5. Acknowledgements

The authors wish to acknowledge all the support provided by Pathumwan Institute of Technology for the realization of this research

Author Contributions: For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used "Conceptualization, ronnarit, Pakamas, Sirawat. and khitaphat; methodology, Pakamas.; software, ronnarit.; validation, ronnarit., Pakamas. and Sirawat.; formal analysis, ronnarit.; investigation, Sirawat; resources, ronnarit., Pakamas., Sirawat.; data curation, khitaphat.; writing—original draft preparation, Pakamas.; writing—review and editing, ronnarit.; visualization, ronnarit;

Funding: This research received no external funding, and no funding was received for the APC.

Conflicts of Interest: The authors declare no conflict of interest. This research received no external funding.

References

[1] Nugraha, R. U.; Susila, A. D. Source as a Substitute for AB Mix in Hydroponic Leafy Vegetable Cultivation. *Indones. J. Hortic.* **2015**, *6*, 11–19. https://doi.org/10.29244/jhi.6.1.11-19

[2] Sapkota, S.; Sapkota, S.; Liu, Z. Effects of Nutrient Composition and Lettuce Cultivar on Crop Production in Hydroponic Culture. *Horticulturae* **2019**, *5*, 72. https://doi.org/10.3390/horticulturae5040072

[3] Chuah, Y. D.; Khor, J. S.; Lim, I. Y.; Ng, C. K. Assessment of Automated Fertigation and Irrigation on the Growth of Bok Choy in a Hydroponic Vertical Farming System. *AIP Conf. Proc.* **2024**, *3161*, 020168. https://doi.org/10.1063/5.0230068

[4] Kano, K.; Kitazawa, H.; Suzuki, K.; Widiastuti, A.; Odani, H. Effects of Organic Fertilizer on Bok Choy Growth and Quality in Hydroponic Cultures. *Agronomy* **2021**, *11*, 491. https://doi.org/10.3390/agronomy11030491

[5] Pearson, C.; Gawel, R.; Maki, D. Effects of Vermicompost and Beneficial Microbes on Biomass and Nutrient Density in Purple Lady Bok Choy in a Vertical Hydroponic System. *Fine Focus* **2023**, *9*, 45–60. https://doi.org/10.33043/FF.9.1.46-64

[6] Gobilik, J.; Rechard, C. T.; Maludin, A. J.; Alam, M. A. Efficacy of Column Hydroponic System for Increasing Growth and Yield of Pak-Choy per Unit Area. *Trans. Sci. Technol.* **2021**, *8*, 60–68.

[7] Veerana, M.; Ketya, W.; Choi, E. H.; Park, G. Non-Thermal Plasma Enhances Growth and Salinity Tolerance of Bok Choy in Hydroponic Culture. *Front. Plant Sci.* **2024**, *15*, 1445791. https://doi.org/10.3389/fpls.2024.1445791

[8] Maluin, F. N.; Hussein, M. Z.; Wayayok, A.; Nik Ibrahim, N. L.; Hashim, N. Chitosan Nanoparticles as a Sustainable Alternative Nutrient Formulation in Hydroponically Grown *Brassica rapa* Microgreen. *Arch. Agron. Soil Sci.* **2023**. https://doi.org/10.1080/03650340.2022.2155952

[9] Ali, A.; Xia, C.; Jia, C.; Faisal, M. Investment Profitability and Economic Efficiency of the Drip Irrigation System: Evidence from Egypt. *Irrig. Drain.* **2020**, *69*, 1033–1050. https://doi.org/10.1002/ird.2511

[10] Jan, S.; Rashid, Z.; Ahngar, T. A.; Iqbal, S.; Naikoo, M. A.; Majeed, S.; Bhat, T. A.; Gul, R.; Nazir, I. Hydroponics—A Review. *Int. J. Curr. Microbiol. Appl. Sci.* **2020**, *9*, 1779–1787. https://doi.org/10.20546/ijcmas.2020.908.206

[11] Wiangsamut, B.; Koolpluksee, M. Yield and Growth of Pak Choi and Green Oak Vegetables Grown in Substrate Plots and Hydroponic Systems with Different Plant Spacing. *Int. J. Agric. Technol.* **2020**, *16*, 491–502.

[12] Manggala, B.; Debra, M.; Chaichana, C.; Syahputra, W. N. H.; Lutfi, M. Effects of Various Hydroponic Systems in Increasing Caisim Productivity under LED Grow Light. *Int. J. Food Agric. Nat. Resour.* **2023**, *4*, 53–58. https://doi.org/10.46676/ij-fanres.v4i2.143

[13] Wiangsamut, B.; Wiangsamut, M. E. L. Assessment of Four Species of Vegetables Grown in Deep Flow Technique and Nutrient Film Technique Hydroponic Systems. *Int. J. Agric. Technol.* **2021**, *17*, 1183–1198.

[14] Salman, A. D.; Abdulrasool, I. J. Effect of Ozone Enrichment and Spraying with Coconut Water and Moringa Extract on Broccoli under Hydroponic System. *Iraqi J. Agric. Sci.* **2022**, *53*, 406–414. https://doi.org/10.36103/ijas.v53i2.1549

[15] Majid, M.; Khan, J. N.; Ahmad Shah, Q. M.; Masoodi, K. Z.; Afroza, B.; Parvaze, S. Evaluation of Hydroponic Systems for the Cultivation of Lettuce and Comparison with Soil-Based Cultivation. *Agric. Water Manage.* **2021**, *245*, 106572. https://doi.org/10.1016/j.agwat.2020.106572

[16] Riggio, G. M.; Jones, S. L.; Gibson, K. E. Risk of Human Pathogen Internalization in Leafy Vegetables during Hydroponic Cultivation. *Horticulturae* **2019**, *5*, 25. https://doi.org/10.3390/horticulturae5010025

[17] Yang, T.; Samarakoon, U.; Altland, J. Growth, Phytochemical Concentration, Nutrient Uptake, and Water Consumption of Butterhead Lettuce in Response to Hydroponic System Design and Growing Season. *Sci. Hortic.* **2024**, *332*, 113201.