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The Application of Nanotechnology-Based Liquid Organic Fertilizer for Improving the Quality of Hydroponically Grown Vegetables

Resti Fevria [a,b,*], Abdul Razak [a], Vauzia [a], Santi Diana Putri [b], Silvy Annisa [a]

[a] Department of Biology, Faculty of Mathematics and Science, Universitas Negeri Padang, Padang, Indonesia
[b] Department Agroindustry, Faculty of Mathematics and Science, Universitas Negeri Padang, Padang, Indonesia

Abstract. *Hydroponics, a farming technique using nutrient-enriched water, has been widely practiced due to its suitability for limited agricultural land. One of the key factors affecting hydroponic efficiency is the nutrient blend, with AB Mix and liquid organic fertilizer playing a crucial role. This study aims to evaluate the potential of nanotechnology-based nutrient solution in hydroponic to enhance nutrient absorption and improve plant growth in different vegetable species. Five vegetable species, which include red lettuce, red spinach, green spinach, pakcoy, and kailan, were selected to assess the interaction between nutrient composition and vegetable species. A study with factorial design was conducted using a randomized complete block design (RCBD). The primary factor was the fertilizer composition and the secondary factor was the type of vegetable. The treatments consisted of Control (Well water + AB Mix), P1 (Nanotechnology water + 100% AB Mix), P2 (Nanotechnology water + 25% nanotechnology liquid organic fertilizer + 75% AB Mix), P3 (Nanotechnology water + 50% nanotechnology liquid organic fertilizer + 50% AB Mix), P4 (Nanotechnology water + 75% nanotechnology liquid organic fertilizer + 25% AB Mix), and P5 (Nanotechnology water + 100% nanotechnology liquid organic fertilizer). Growth parameters measured included plant height, fresh weight, dry weight, number of leaves, and leaf area. Data were evaluated using a two-way ANOVA to assess the effects of fertilizer composition and vegetable type, followed by a 5% DMRT test for mean comparison. The findings indicated that the use of liquid organic fertilizer technology influenced plant growth. The most optimal average growth was recorded in the P2 treatment (a combination of nanotechnology water, 25% nanotechnology liquid organic fertilizer, and 75% AB Mix), while the least favorable result was observed in P5 (nanotechnology water combined with 100% nanotechnology liquid organic fertilizer).*

Keywords: *nanotechnology; hydroponics; vegetables; growth.*

Type of the Paper: Regular Article.

1. Introduction

The Indonesian population has consistently increased. According to the 2022 statistical data, approximately 275 million people, or 56.7%, reside in urban areas. The limited agricultural land is one of the factors contributing to the difficulty in meeting the population's food needs. An increase in population will lead to an increased demand for food, particularly vegetables [1]. As recent studies highlight, urban farming has become a potential solution to improve food security [2], especially in major Indonesian cities, through efficient land use and alternative farming

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* First corresponding author
Email: restifevria@fmipa.unp.ac.id

techniques such as hydroponics [3]. Hydroponic planting is a method which can be applied to narrow land, enabling crop production to meet the community's food needs [4]. This method has been extensively explored in urban farming research, as demonstrated by Latue et al., where hydroponic farming is shown to effectively utilize limited land for growing various crops, contributing to food security and local economic development [5]. The characteristic of hydroponic cultivation is that it does not use soil; instead, the soil medium is replaced with water supplemented with a high-nutrient solution to provide adequate plant nutrition. Hydroponics can yield environmentally friendly products because the source of nutrients is derived from organic materials [6].

AB Mix is a widely used nutrient solution in hydroponic farming, containing both macro and micronutrients that aim to fulfill the nutritional requirements of plants [7]. In addition to AB Mix, liquid organic fertilizer can also be utilized in hydroponic cultivation as a nutrient solution. This fertilizer is composed of ecoenzymes or fermented organic waste [8]. The liquid organic fertilizer contains iron, manganese, calcium, magnesium, boron, molybdenum, sodium, phosphorus, potassium, sulfate, and magnesium [9]. However, hydroponic cultivation has some drawbacks, one of which is the uneven distribution of nutrients due to limited circulation. This can result in nutrient precipitation at the bottom of the hydroponic system, leading to moss growth and adversely affecting plant development [10,11]. To address this issue, nanotechnology-based nutrient solutions have been shown to enhance nutrient absorption efficiency, ultimately improving plant growth in hydroponic systems [12].

The nutrients that plants consume vary according to their growth stage [13]. The need for plant nutrients must be appropriately met to reduce the occurrence of precipitation in the hydroponic system by applying nanotechnology to the planting media and nutrient solutions used [14]. The development of this technology is one of renewable innovations to address agricultural problems. Nanotechnology is an innovation which changes particles into nanometer sizes [15]. The application of nanotechnology to fertilizers affects the release of fertilizer particles, which is more controlled and prevents plants from experiencing nutritional deficiencies due to the maintained nutrient content of fertilizers. The release of fertilizer in the planting medium occurs in the form of nanomaterials, which are released as nanoparticles [16]. Nanofertilizers, which utilize nanotechnology, have been proven to improve the efficiency of nutrient absorption in plants and minimize nutrient loss to the environment, thus contributing to more sustainable agriculture [17].

Numerous studies have been conducted on the application of nanotechnology in plant protection and assessed the efficacy of liquid organic fertilizer based on nanotechnology in hydroponic systems by evaluating plant growth [18]. Various nanomaterials have shown significant effects on seed germination rates, plant height, number of leaves, root length and count, as well as fresh and dry biomass accumulation. In addition, nano-fertilizers have been reported to enhance nutrient uptake efficiency, improve plant productivity, and promote soil health, while also minimizing environmental impact, making them a promising solution for sustainable agriculture [19,20]. The application of nanotechnology in previous studies indicates a significant effect on plant growth; therefore, it is necessary to research other types of horticultural plants to determine the effect exerted by nanotechnology-based liquid organic fertilizer on the growth of plants cultivated hydroponically. Nanotechnology monitors substances, materials, and systems at the nanoscale, providing innovative results. It can accelerate sustainable agricultural growth through advanced techniques such as nanotechnology [21]. Therefore, the purpose of this study is to examine its effects on plant growth parameters, including plant height, fresh weight, dry weight, number of leaves, and leaf area.

2. Materials and Methods

This study employed a Factorial Randomized Complete Block Design (Factorial RCBD) with two factors: fertilizer composition (Table 1) and vegetable species. The vegetable species consisted of red lettuce (*Lactuca sativa* var. *acephala*), red spinach (*Amaranthus tricolor* L.), green spinach (*Amaranthus hybridus* L.), pakcoy (*Brassica rapa*), and kailan (*Brassica oleracea*). Each treatment combination was randomly assigned within experimental blocks to control for environmental variability, ensuring that all vegetable species received every fertilizer treatment.

The study was conducted at the Wire House, Department of Biology, Universitas Negeri Padang from April to August 2024, under controlled environmental conditions suitable for hydroponic cultivation. Temperature, humidity, and light exposure were monitored to maintain optimal growth conditions for the tested vegetable species.

2.1. Manufacturing of Nanotechnology Liquid Organic Fertilizer

Nanotechnology-based liquid organic fertilizer was derived from organic fruit waste through anaerobic fermentation, utilizing a mixture of water and brown sugar. The process used a 1:3:10 ratio of sugar, fruit waste, and water, which was then allowed to ferment under oxygen-limited conditions for three months. This fermentation period enables microbial activity to break down organic matter and enhance nutrient availability [22].

After fermentation, the mixture was filtered to separate the solid residues from the liquid. The filtered liquid organic fertilizer was then processed into a nanotechnology-based fertilizer using a nanobubble aerator, generating ultrafine gas bubbles that improved nutrient dispersion and absorption efficiency [23]. The final product was stored in an airtight container at room temperature to prevent contamination and nutrient degradation.

2.2. Preparation of Planting Media and Seeding

The planting medium was prepared using Rockwool, AB Mix solution, water, liquid organic nanotechnology fertilizer, plant seeds, seeding trays, a TDS meter, a pH meter, and a hydroponic system.

In the first stage, Rockwool cubes measuring 2×2×2 cm were cut and moistened with water to create optimal conditions for seed germination. A small hole was made in each Rockwool cube, and a single seed was carefully inserted. The seeded Rockwool cubes were covered with black plastic to maintain darkness and placed in an area without direct sunlight. After 24 hours, the covering was removed, and the seedlings were exposed to sufficient sunlight for 7 to 8 days until they developed four true leaves, indicating their readiness for transplantation.

After reaching an adequate stage of growth, the seedlings were relocated to a hydroponic setup employing the Nutrient Film Technique (NFT), a system that circulates a thin layer of nutrient-rich water along the root zone. This system accommodated a total of 6 liters of planting medium, filled with an equal volume of water enriched with nutrients: 5 ml/L of solution A, 5 ml/L of solution B, and 50 ml/L of liquid organic fertilizer. The continuous nutrient flow within the NFT system provided consistent oxygen and nutrient availability to the roots while minimizing water stagnation, an advantage that makes this method widely favored in both research and commercial hydroponic practices [4]. Daily monitoring of pH and electrical conductivity (in ppm) was performed using a pH meter and a TDS meter to maintain ideal growth conditions. The research design outlining the composition of each treatment in the planting medium is presented in Table 1.

Table 1. The research design for the composition of each treatment on the planting medium

Experiment Design	
Research Treatment	Composition
Control	Well Water + AB *Mix*
P1	Nano Water + 100% AB *Mix*
P2	Nano Water + 25% nanotechnology liquid organic fertilizer + 75% AB *Mix*
P3	Nano Water + 50% nanotechnology liquid organic fertilizer + 50% AB *Mix*
P4	Nano Water + 75% nanotechnology liquid organic fertilizer + 25% AB *Mix*
P5	Nano Water + 100% nanotechnology liquid organic fertilizer

2.3. Measurement Parameters

Plant measurements consist of several parameters. Plant height (cm) was measured every three days, starting from one week after planting until the plants reached four weeks of age. The number of leaves (sheet) was measured weekly at one, two, three, and four weeks after planting. Only fully developed leaves, defined as those with a complete shape and fully expanded surface, were included in the count. Leaf area (cm^2) was measured at four weeks after planting by assessing all leaves, except for the first two leaves that emerged during germination. The fresh weight (g) was recorded in the fourth week after planting by weighing the entire plant, including roots, stems, and leaves. Dry weight (g) was also measured in the same week by drying all plant components, which included leaves, stem, and roots, in an oven at 60°C until a constant weight was reached.

2.4. Data Analysis

The collected data were subjected to analysis of variance (ANOVA). If significant differences were found, further comparisons were conducted using Duncan's New Multiple Range Test (DMRT) at a 5% significance level.

3. Results and Discussion

3.1. Plant Height

The ANOVA test conducted at the 5% level indicated a significant difference in the plant height data. A follow-up test using DMRT at the 5% level showed that the highest plant height was found in the P4 treatment of red spinach, with a value of 37.2 cm, while the lowest was recorded in the P5 treatment of pakcoy, with a value of 9.27 cm. These results are shown in Fig. 1.

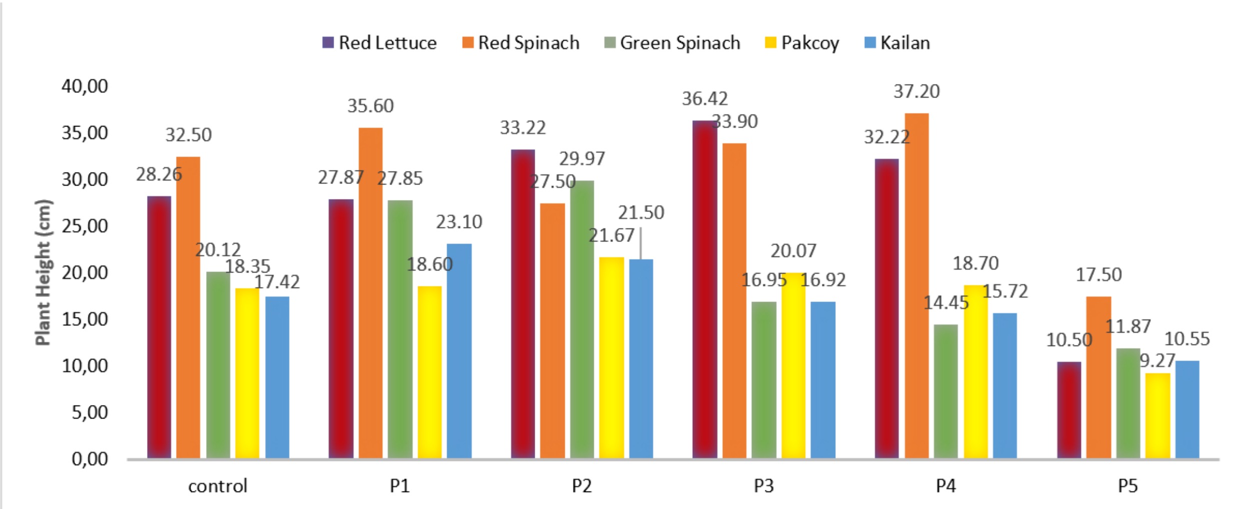

Fig. 1. The comparison of Plant Height of five species of vegetables in the present study

3.2. Fresh Weight

The ANOVA test conducted at the 5% level indicated a significant difference in the fresh weight data. A follow-up test using DMRT at the 5% level showed that the highest fresh weight was recorded in the P2 treatment of pakcoy plants, with a value of 20.15 grams, while the lowest was recorded in the P2 treatment of red spinach, with a value of 0.48 grams. The highest fresh weight observed in treatment P2 can be attributed to the ability of liquid organic fertilizer to enhance the planting medium's capacity to regulate temperature, thereby ensuring a sustainable supply of nutrients. These results are shown in Fig. 2.

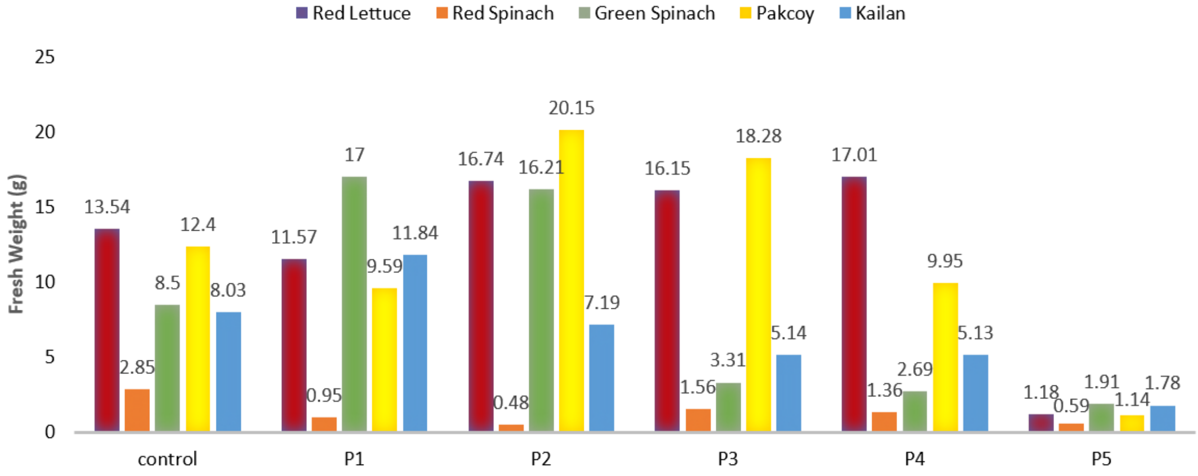

Fig. 2. The comparison of fresh weight of five species vegetables in the present study

3.3. Dry Weight

The ANOVA test conducted at the 5% level indicated a significant difference in the dry weight data. A follow-up test using DMRT at the 5% level showed that the highest dry weight was found in the P2 treatment of pakcoy plants, with a value of 1.33 grams, while the lowest was recorded in the P5 treatment of red spinach, with a value of 0.007 grams. Giving liquid organic fertilizer at excessively high concentrations can lead to plasmolysis in plants, resulting in suboptimal growth, as observed in treatment P5. These results are shown in Fig. 3.

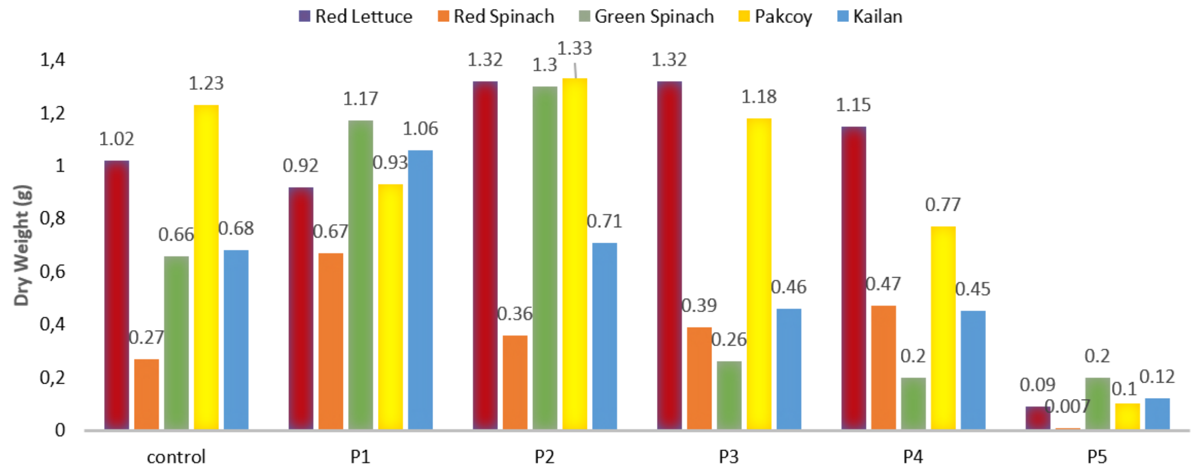

Fig. 3. The comparison of dry weight of five species vegetables in the present study

3.4. Number of Leaves

The ANOVA test conducted at the 5% level indicated a significant difference in the number of leaves. A follow-up test using DMRT at the 5% level showed that the highest number of leaves was found in the P2 treatment of green spinach, with a value of 34 strands, while the lowest was recorded in the P5 treatment of kailan, with a value of 4.25 strands. The natural hormones present in nanotechnology-based liquid organic fertilizers can stimulate root growth, thereby enhancing overall plant development. These results are shown in Fig. 4.

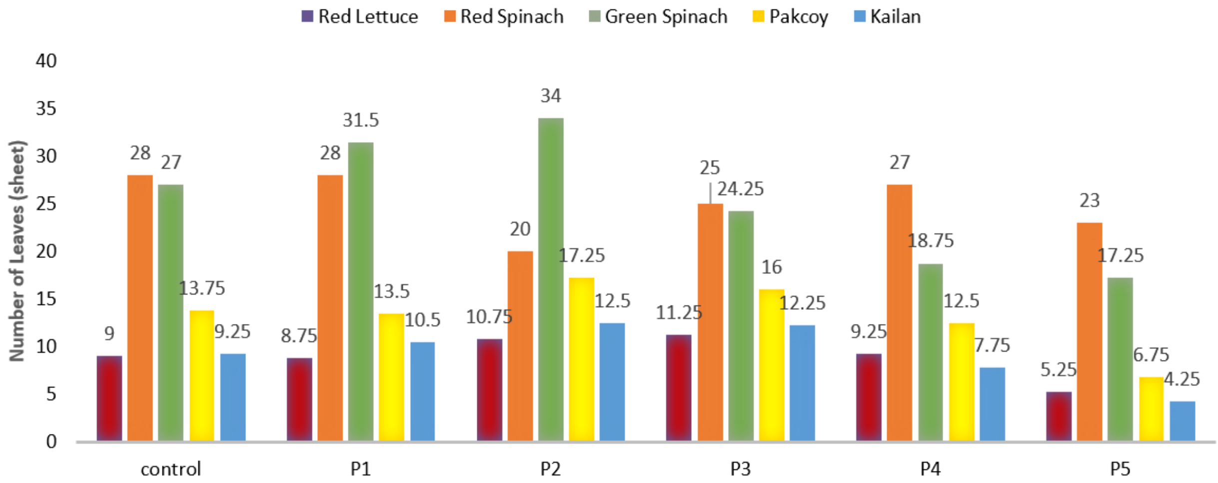

Fig. 4. The comparison of number of leaves of five species vegetables in the present study

3.5. Leaf Area

The ANOVA test conducted at the 5% level indicated a significant difference in the leaf area. A follow-up test using DMRT at the 5% level showed that the highest number of leaves was found in the P4 treatment of red lettuce, with a value of 40.25 cm^2, while the lowest was recorded in the P5 treatment of green spinach, with a value of 2.02 cm^2. The appropriate dosage of fertilizer significantly influences the optimal leaf area for plants. Administering fertilizer in accordance with the recommended dosage will affect optimal plant growth. In the case of red lettuce, optimal plant growth is achieved at treatment P4. The data are presented in Fig. 5.

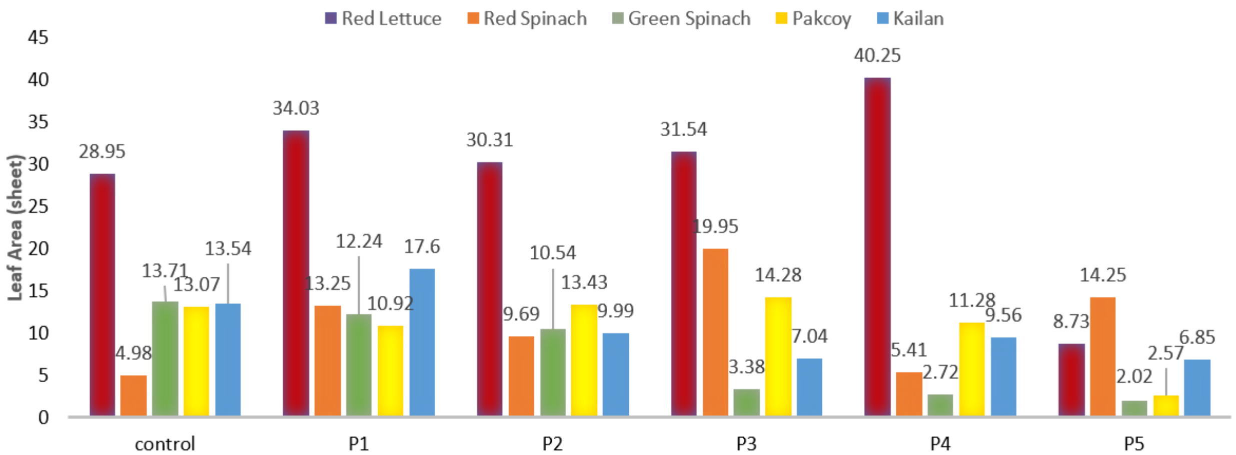

Fig. 5. The comparison of leaf area of five species vegetables in the present study

Following the ANOVA, Duncan's Multiple Range Test (DMRT) at the 5% significance level was performed to identify treatment groups with statistically significant differences. A recapitulation of the DMRT test results for all observed parameters in each vegetable type is provided in Table 2.

Table 2. Recapitulation of DMRT Test Results for All Growth Parameters and Vegetable Types

Parameter	Treatment	Red Lettuce		Red Spinach		Green Spinach		Pakcoy		Kailan	
		Mean	Symbol	Mean	Symbol	Mean	Symbol	Mean	Symbol	Mean	Symbol
Plant Height	P1	27.875	b	7.1	a	14.45	a	18.6	b	23.1	c
	P2	33.225	bc	15.85	ab	16.95	a	21.675	d	21.5	c
	P3	36.425	c	15.95	b	20.125	ab	20.075	c	16.925	b
	P4	32.225	bc	17.6	bc	27.85	bc	18.7	b	15.725	b
	P5	10.5	a	18.9	c	29.975	c	9.275	a	10.55	a
Fresh Weight	P1	11.575	b	1.76	a	2.6975	a	9.5925	b	11.8425	c
	P2	16.743	b	2.0525	ab	3.315	a	20.1525	c	7.1925	b
	P3	16.153	b	2.575	b	8.5	a	18.26	c	5.1425	ab
	P4	17.015	b	3.75	bc	16.21	b	9.955	b	5.13	ab
	P5	1.18	a	3.75	c	17	b	1.145	a	1.7825	a
Dry Weight	P1	0.9225	b	0.6325	a	0.2075	a	0.9325	bc	1.0675	c
	P2	1.325	b	0.6925	a	0.2625	a	1.335	d	0.7125	bc
	P3	1.32	b	1.0825	ab	0.66	a	1.18	cd	0.465	ab
	P4	1.155	b	1.5225	b	1.174	b	0.77	b	0.4525	ab
	P5	0.0925	a	1.545	b	1.3	b	0.1075	a	0.21	a
Number of Leaves	P1	8.75	b	6.5	ab	18.75	a	13.5	bc	10.5	cd
	P2	10.75	b	8.25	b	24.25	ab	17.25	d	12.5	e
	P3	11.25	b	8.75	b	27	ab	16	cd	12.25	de
	P4	9.25	b	8.75	b	31.5	bc	12.5	b	7.75	b
	P5	5.25	a	9.25	c	34	c	6.75	a	4.25	a
Leaf Area	P1	34.033	b	68.91	ab	2.7225	a	10.9225	b	17.6	b
	P2	30.318	b	75.755	bc	3.385	a	13.43	bc	9.995	a
	P3	31.548	b	151.205	cd	10.54	b	14.28	c	7.0425	a
	P4	40.253	b	208.455	d	12.24	b	11.2825	b	9.5625	a
	P5	8.7375	a	239.475	d	13.71	c	2.575	a	6.8575	A

Microorganisms degrade nanotechnology-based liquid organic fertilizers into simpler compounds, enhancing nutrient accessibility and absorption by plant roots compared to chemical fertilizers, which require decomposition. This finding aligns with the work of Phibunwatthanawong and Riddech, who demonstrated that microbial activity in liquid organic fertilizers enhances plant growth in hydroponic systems by increasing nutrient bioavailability, thereby improving nutrient uptake efficiency [24].

The nutritional composition provided plays a crucial role in the growth of hydroponically grown plants. The use of nanotechnology liquid organic fertilizer has a significant effect on plant growth, with the most effective compositions being P2 (25% nanotechnology liquid organic fertilizer + 75% AB Mix) and P3 (50% nanotechnology liquid organic fertilizer + 50% AB Mix). According to a study by Marginingsih et al. [25], the mixture of 25% and 50% AB Mix promotes optimal plant growth. By blending AB Mix with liquid organic fertilizer, the plants' macro and micronutrient needs are met, which are essential for supporting physiological and metabolic processes. Similar findings were reported by Muhadiansyah et al. [26] who observed that a 50% AB Mix and 50% liquid organic fertilizer mixture positively influenced plant growth, as shown by increased leaf count and overall plant weight. Additionally, lettuce plant development was enhanced by the mixture of 75% AB Mix and 25% liquid organic fertilizer.

The mixture of AB Mix and liquid organic fertilizer enhanced with nanotechnology has a significant influence on plant growth. According to Fevria et al. [27], hydroponically grown vegetables showed enhanced nutritional quality compared to those grown non-hydroponically. Similarly, the concentration of AB Mix is positively correlated with plant development, where higher concentrations tend to optimize growth [28]. However, excessive nutrient application can lead to phytotoxicity, which is often indicated by changes in leaf coloration. Exceeding nutrient concentrations beyond the specific requirements of the plant may lead to reduced growth and impaired nutrient uptake [29]. This phenomenon occurs because an overly concentrated solution can limit the absorption process and overall plant development, as demonstrated in the study by Nasir and Sato [30] on hydroponic tomato cultivation with varying nutrient levels.

The application of nanotechnology-based liquid organic fertilizers to plant media is closely related to microorganisms that enhance the nutritional quality of the growing medium and support plant growth. This study indicates that treatment P5 (100% liquid organic fertilizer with nanotechnology) resulted in a significantly lower growth rate compared to other treatments. The application of nanotechnology-based liquid organic fertilizers can have a substantial impact on plant growth, with effects varying from low to high concentrations. Research has demonstrated that increased concentrations of liquid organic fertilizers, including those utilizing nanotechnology, can lead to stunted development. This phenomenon is attributed to the emergence of antagonistic effects that do not benefit plant growth [31]. Furthermore, the pH of liquid organic fertilizer typically ranges from 3 to 5, primarily due to the lactic acid produced by microorganisms during the fermentation process. High-quality liquid organic fertilizers generally maintain a pH of around 5.

Nanotechnology can enhance hydroponic plant growth by reducing particles to a nanoscale with the assistance of a nanobubble aerator. The nanostructure of the particles produced by the nanotechnology has better capabilities than the previous particle structure; the use of nanotechnology is more effective because it has a nano size [32]. Research suggests that reducing the particle size of raw materials alters the properties of fertilizers, allowing them to be more easily absorbed by leaf cell membranes. This improves absorption, fertilizer quality, and the productivity of corn plants. According to research by Kyebogola et al. [33], nanotechnology has been shown to enhance fertilizer absorption in plants, improving the efficiency of nutrient uptake. This improvement is largely due to the use of slow-release fertilizers (SRF) that regulate the gradual release of nutrients, allowing for a more consistent and efficient absorption pattern by the plants.

4. Conclusions

Each vegetable responded optimally to different treatments. Red lettuce performed best under P3 and P4, with most parameters peaking at P3. Red spinach showed optimal growth in P3 and P4, although several parameters were highest under the control and P1. Green spinach had the best results in P1 and P2, with most growth parameters peaking at P2. Pakcoy consistently showed optimal growth in P2, except for leaf area, which was best in P3. Kailan performed best in P1 and P2, with the majority of parameters highest in P1. In general, **P2** (a combination of 25% nanotechnology-based liquid organic fertilizer and 75% AB Mix) proved to be the most effective treatment for promoting vegetative growth across different vegetable types in wick-based hydroponic cultivation systems. The organic matter content in each liquid organic fertilizer can yield different results on plant growth. Future research should focus on the organic matter content in liquid organic fertilizers, as it can significantly affect plant growth.

Abbreviations

AB	Mix A and B nutrient mix
RCBD	Randomized complete block design
DMRT	Duncan’s multiple range test
TDS	Total dissolved solids
NFT	Nutrient film technique
SRF	Slow-release fertilizer

Data availability statement

The data will be provided upon readers' request.

Credit authorship contribution statement

Resti Fevria: Conceptualization, Methodology, Resources, Formal analysis, Investigation, Data curation, Writing – review & editing. **Abdul Razak**: Writing – original draft, Validation, Data curation, Formal analysis, Conceptualization.**Vauzia**: Conceptualization, Supervision, Project administration. **Santi Diana Putri**: Resources, Writing – review & editing. **Silvy Annisa:** Writing – review & editing, Formal analysis.

Declaration of Competing Interest

The authors of this manuscript state that they have no conflicts of interest or competing interests.

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References

[1] Peters CJ, Picardy J, Darrouzet-Nardi AF, Wilkins JL, Griffin TS, Fick GW. Carrying capacity of U.S. agricultural land: Ten diet scenarios. Elementa 2016;2016:1–15. https://doi.org/10.12952/journal.elementa.000116.

[2] Hartanto I, Fevria R. Analysis of kale (Brasicca oleraceae) crop cultivation using verticulture method in the city of padang panjang. J Phys Conf Ser 2019;1317. https://doi.org/10.1088/1742-6596/1317/1/012073.

[3] Abdillah A, Widianingsih I, Buchari RA, Nurasa H. Implications of urban farming on urban resilience in Indonesia: Systematic literature review and research identification. Cogent Food Agric 2023;9. https://doi.org/10.1080/23311932.2023.2216484.

[4] Rajaseger G, Chan KL, Tan KY, Ramasamy S, Khin MC, Anburaj A, et al. Hydroponics: current trends in sustainable crop production. Bioinformation 2023;19:925–938. https://doi.org/10.6026/97320630019925.

[5] Latue T, Latue PC, Rakuasa H. Bandung Gardening: Hydroponic Salads. Nusant J Behav Soc Sci 2023;2:25–30. https://doi.org/10.47679/202330.

[6] Fevria R, Farma SA, Vauzia, Edwin, Purnamasari D. Comparison of Nutritional Content of Spinach (Amaranthus gangeticus L.) Cultivated Hydroponically and Non-Hydroponically. Eksakta Berk Ilm Bid MIPS 2021;22:46–53. https://doi.org/10.24036/eksakta/vol22-iss1/243.

[7] Yulia AE, Murniati, Dini IR, Manja L. The effect of combination of AB-mix nutrition with liquid organic fertilizer of tofu liquid waste on hydroponical growth and production of lettage (Lactuca sativa L.). Int J Sci Res Arch 2021;4:165–170. https://doi.org/10.30574/ijsra.2021.4.1.0190.

[8] Sugiarto Y, Nugrayani TR, Hakim L, Djoyowasito G, Zhang J. Enhancing spinach (Amaranthus tricolor L.) growth using maggot fermentation-derived liquid organic fertilizer and AB mix in drip fertigation systems. J Keteknikan Pertan Trop dan Biosist 2024;12:105–113. https://doi.org/10.21776/ub.jkptb.2024.012.02.04.

[9] Haryanta D, Sa'adah TT, Thohiron M, Rejeki FS. Utilization of urban waste as liquid

organic fertilizer for vegetable crops in urban farming system. Plant Sci Today 2023;10:120–128. https://doi.org/10.14719/pst.2028.
[10] Zhang C, Xiao H, Du Q, Wang J. Hydroponics with split nutrient solution improves cucumber growth and productivity. J Soil Sci Plant Nutr 2023;23:446–455. https://doi.org/10.1007/s42729-022-01056-8.
[11] Baiyin B, Tagawa K, Yamada M, Wang X, Yamada S, Shao Y, et al. Effect of nutrient solution flow rate on hydroponic plant growth and root morphology. Plants 2021;10:1–11. https://doi.org/10.3390/plants10091840.
[12] Putri RME, Fevria R, Violita, M D. Effect of nano technology ecoenzyme on the growth of pakcoy (Brassica rapa L .) cultivated hydroponically. J Produksi Tanam 2023;11:349–358. https://doi.org/10.21776/ub.protan.2023.011.06.01.
[13] Sangeetha T, Periyathambi E. Automatic nutrient estimator: distributing nutrient solution in hydroponic plants based on plant growth. PeerJ Comput Sci 2024;10:1–28. https://doi.org/10.7717/peerj-cs.1871.
[14] Sambo P, Nicoletto C, Giro A, Pii Y, Valentinuzzi F, Mimmo T, et al. Hydroponic solutions for soilless production systems: Issues and opportunities in a smart agriculture perspective. Front Plant Sci 2019;10. https://doi.org/10.3389/fpls.2019.00923.
[15] Achari GA, Kowshik M. Recent developments on nanotechnology in agriculture: Plant mineral nutrition, health, and interactions with soil microflora. J Agric Food Chem 2018;66:8647–8661. https://doi.org/10.1021/acs.jafc.8b00691.
[16] Usman M, Farooq M, Wakeel A, Nawaz A, Cheema SA, Rehman H ur, et al. Nanotechnology in agriculture: Current status, challenges and future opportunities. Sci Total Environ 2020;721:137778. https://doi.org/10.1016/j.scitotenv.2020.137778.
[17] Fevria R, Razak A, Heldi, Syah N, Kamal E, Edwin. Application of nanotechnology liquid organic fertilizer in sustainable hydroponic cultivation for urban food security. Sci Technol Asia 2023;28:295–304. https://doi.org/10.14456/scitechasia.2023.89.
[18] Shang Y, Hasan MK, Ahammed GJ, Li M, Yin H, Zhou J. Applications of nanotechnology in plant growth and crop protection: A review. Molecules 2019;24. https://doi.org/10.3390/molecules24142558.
[19] Zulfiqar F, Navarro M, Ashraf M, Akram NA, Munné-Bosch S. Nanofertilizer use for sustainable agriculture: Advantages and limitations. Plant Sci 2019;289:110270. https://doi.org/10.1016/j.plantsci.2019.110270.
[20] Mirbakhsh M. Role of nano-fertilizer in plants nutrient use efficiency (NUE). J Genet Eng Biotechnol Res 2023;5:75–81. https://doi.org/10.33140/jgebr.05.02.01.
[21] Prasad R, Bhattacharyya A, Nguyen QD. Nanotechnology in sustainable agriculture: Recent developments, challenges, and perspectives. Front Microbiol 2017;8:1–13. https://doi.org/10.3389/fmicb.2017.01014.
[22] Hemalatha M, Visantini P. Potential use of eco-enzyme for the treatment of metal based effluent. IOP Conf Ser Mater Sci Eng 2020;716. https://doi.org/10.1088/1757-899X/716/1/012016.
[23] Wang Y, Wang S, Sun J, Dai H, Zhang B, Xiang W, et al. Nanobubbles promote nutrient utilization and plant growth in rice by upregulating nutrient uptake genes and stimulating growth hormone production. Sci Total Environ 2021;800:149627. https://doi.org/10.1016/j.scitotenv.2021.149627.
[24] Phibunwatthanawong T, Riddech N. Liquid organic fertilizer production for growing vegetables under hydroponic condition. Int J Recycl Org Waste Agric 2019;8:369–380. https://doi.org/10.1007/s40093-019-0257-7.
[25] Marginingsih RS, Nugroho AS, Dzakiy MA. Pengaruh substitusi pupuk organik cair pada nutrisi AB mix terhadap pertumbuhan caisim (Brassica juncea L.) pada hidroponik drip irrigation system. J Biol dan Pembelajarannya 2018;5:44–51. https://doi.org/10.29407/jbp.v5i1.12034.
[26] Muhadiansyah TO, Setyono, Adimihardja SA. Efektivitas pencampuran pupuk organik cair

dalam nutrisi hidroponik pada pertumbuhan dan produksi tanaman selada (Lactuca sativa L.). J Agronida 2016;2:37–46. https://doi.org/10.30997/jag.v2i1.749.

[27] Fevria R, Aliciafarma S, Vauzia, Edwin. Comparison of nutritional content of water spinach (Ipomoea aquatica) cultivated hydroponically and non-hydroponically. J Phys Conf Ser 2021;1940:012049. https://doi.org/10.1088/1742-6596/1940/1/012049.

[28] Subakti MR, Nurhayati, Rahayu MS. The effect of concentration of ab mix and zpt solutions on the growth and production of mustard plants (Brassica juncea L.) in hydroponic wick systems. E3S Web Conf 2022;339:2–8. https://doi.org/10.1051/e3sconf/202233901010.

[29] Park HB, Park SY, Park IS, Jang IB, Hyun DY, Lee CW, et al. Influence of nutrient solution concentration on growth and tissue mineral content of Panax ginseng seedlings cultured in a root medium containing peat and perlite. Hortic Environ Biotechnol 2020;61:715–724. https://doi.org/10.1007/s13580-020-00262-6.

[30] Nasir N, Sato T. Effect of nutrient solution concentration on growth, yield, and fruit quality of tomato grown hydroponically in single-truss production system. J Hortic Res 2023;31:127–144. https://doi.org/10.2478/johr-2023-0034.

[31] Andrian D, Tantawi AR, Rahman A. The use of liquid organic fertilizer as growth media and production of kangkung (Ipomoea reptans Poir) hydroponics. Budapest Int Res Exact Sci J 2019;1:23–34. https://doi.org/10.33258/birex.v1i1.132.

[32] Sari VI, Maarif MS, Arkeman Y. Inovasi teknologi nano untuk composting tandan kosong kelapa sawit. J Tek Ind 2014;4. https://doi.org/10.25105/jti.v4i2.1556.

[33] Kyebogola S, Kabiri S, Onwonga RN, Semalulu O, Yost RS, Sseruwu G. Greener Production and Application of Slow-Release Nitrogen Fertilizer Using Plasma and Nanotechnology: A Review. Sustain 2024;16. https://doi.org/10.3390/su16229609.