Jurnal Kultivasi Vol. 23 (3) December 2024
ISSN: 1412-4718, eISSN: 2581-138x

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The Role of nutrient solutions on phosphate-solubilizing bacteria population, phosphorus availability, phosphorus uptake, growth and yield of red chili (*Capsicum annuum* L.)

Abstract. Red chili consumption in Indonesia has increased every year. However, with large chili production to meet large consumption, land conversion for various purposes has reduced the harvested area. The efforts to increase the harvested area of chili using Inceptisols soil by providing nutrient solutions to overcome the infertility of the soil using its nutrients. This experiment aims to determine the effect of nutrient solution application on population of phosphate-solubilizing bacteria, phosphorus availability, phosphorus uptake, growth and yield of Red Chili (*Capsicum annuum* L.) in Inceptisols. The experiment was conducted from August 2023 to February 2024 at Ciparanje Experimental Field, Faculty of Agriculture, Padjadjaran University, and the analysis process was conducted at the Laboratory of Soil Biology, and Soil Chemistry and Plant Nutrition, Department of Soil Science and Land Resources, Faculty of Agriculture, Universitas Padjadjaran., using a factorial randomized block design with two factors, nutrient solutions concentrates (1200, 1600, 2000 ppm) and nutrient solutions doses (200, 400, 600 mL), resulting in nine treatments and three replications. The results showed that the treatment of nutrient solution concentration and dose increased the number of fruits per plant, fruits weight per plant, and yield of chili with grade A. Treatment with 2000 ppm concentrate + 600 mL dose gave the best results on the number of fruits per plant (44.7 fruits), fruit weight per plant (725g), and grade A chili yield (73 fruits).

Keywords: Inceptisols · Nutrients · Phosphate · Red chilli

Submitted: 31 October 2024, Accepted: 11 December 2024, Published: 15 December 2024
DOI: https://doi.org/10.24198/kultivasi.v23i3.58764

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Fitriatin BN, Ghifari RFH, Sofyan ET, Widiantini F, Fakhrurroja H, Simarmata T. 2024. The Role of nutrient solutions on phosphate-solubilizing bacteria population, phosphorus availability, phosphorus uptake, growth and yield of red chili (*Capsicum annuum* L.). Jurnal Kultivasi, 23(2): 354-363.

Introduction

Red chili plants are very important in cultivation because of the high demand for their products. Quoted from data from the Central Statistics Agency (2024), there was an increase in red chili production in 2022 to 2023. In 2022, the amount of large red chili production in Indonesia was 1,475,821 tons, which increased by 5.33% or 78,667 tons to 1,554,498 tons in 2023. The increase in the amount of large red chili production in Indonesia was accompanied by a decrease in the harvest area for this commodity.

The large number of land conversions, opening of industrial areas, and residential areas are factors causing the decrease in the area of agricultural harvest land in Indonesia (Ivanka et al., 2024). Stringer et al. (2020) stated that creating potential land by utilizing existing land with various methods such as urban farming can be a solution to overcome the decrease in the area of harvest land.

The land with a fairly large area in Indonesia is the Inceptisols soil order, with an area of around 40% of the total land area in the country (Muslim et al., 2020). In tropical countries, Inceptisols plains that experience drought will experience a decrease in organic matter levels, so that their fertility is relatively low (Suwardi, 2019). One effort to overcome this problem can be done by applying organic fertilizers along with inorganic fertilizers to improve soil fertility. One example of inorganic fertilizer is a ready-to-absorb nutrient solution.

Phosphorus is a nutrient that helps in biochemical and physiological reactions of plants (Khan et al., 2023). Vasconcelos et al. (2022) stated that phosphorus plays an important role in plant respiration, photosynthesis, plant metabolism, where phosphorus as an essential nutrient certainly helps to encourage plant growth. Malhotra, et al. (2018) stated that phosphorus for plants functions to help assimilation, accelerate seed ripening and flowering, and stimulate root growth. With the important role of phosphorus in plant growth and development, the lack of phosphate availability that can be absorbed by plants is a problem because only 0.01% of the total P solubility can be absorbed by plants (Bhat et al., 2024).

One way to increase the levels of dissolved phosphorus that can be absorbed by plants is by using Phosphate Solubilizing Bacteria (PSB). Phosphate solubilizing bacteria can make previously insoluble phosphate become dissolved and can be absorbed by plants. Fitriatin, et al. (2022) explained that phosphate solubilizing bacteria make the use of organic phosphorus fertilizer more efficient, which helps plants by increasing the concentration of plant phosphorus and overcoming the lack of phosphorus availability. Based on the description above, the purpose of this research to study nutrient solutions with the right concentration and dosage to increase the population of phosphate solubilizing bacteria, phosphorus availability, phosphorus absorption, and the productivity and yield of red chilies in soil media in polybags.

Materials and Methods

The materials were used red chili seeds of the F1 pillar variety, nutrient solution contain of macro and micronutrients, Inceptisols soil (pH organic of 6.05 (slightly acidic); organic carbon of 1.5% (low); total nitrogen of 0.23% (medium); potential phosphorus of 640.2 mg 100 g^{-1} (very high); phosphorus availability of 1.035 ppm (very low); cation exchange capacity of 23.78 cmol kg^{-1} (medium); and a population of phosphate-solubilizing bacteria 36 x 10^7 CFU mL^{-1} (medium), manure and biocar-based bioameliorant enriched with *Trichoderma* sp. The design used in this experiment is a Factorial Randomized Block Design. There were two factors in this design, with the first factor being the treatment of nutrient solution concentration (1200, 1600 and 2000 ppm) and the second factor being the dose of nutrient solution (200, 400 and 600 mL). There were nine treatment combinations, where each treatment was repeated in three replications. The nutrient solution is given every 3 days with a dose of nutrient solution according to the treatment.

The observations conducted in this study include primary and supporting observations. The primary observation variables in this research are as follows:

1. The population of phosphate-solubilizing bacteria in the soil was assessed using the total plate count (TPC) method with Pikovskaya medium. Observations were made during the destruction of plants at the end of the vegetative phase or at eight weeks after planting (WAP).
2. Phosphorus availability was measured using the Olsen method, with observations also

ISSN: 1412-4718, eISSN: 2581-138x

conducted during plant destruction at eight WAP.

3. Phosphorus uptake was determined using the wet ash method, with measurements taken at the same time as plant destruction.
4. The dry weight of the plants was measured using the oven-drying method, also during plant destruction at eight WAP.
5. The growth of chili plants, including the number of leaves, plant height (cm), and stem diameter (mm), was observed every two weeks during the vegetative phase, from two to four WAP.
6. The yield of chili plants over eight harvests, including the number of fruits per plant and total fruit weight (g), was measured using scales and rulers at harvest time.
7. The quality of the chili yields (Grade A, B, C) was classified based on Indonesian National Standards and was assessed during harvest.

The data from the study were statistically analyzed using a Factorial Randomized Block Design (FRBD), employing the SPSS application to conduct a normality test to determine the normal distribution of the data. If the results of the normality test indicate a normal distribution, the analysis will proceed with analysis of variance (ANOVA) at a significance level of 5% to assess the effects of the treatments (whether they are significant or not). If the ANOVA results show a significant effect, it will be followed by Duncan's Multiple Range Test (DMRT) at a significance level of 5%.

Results and Discussion

Phosphorus Availability and Phosphate-solubilizing Bacteria Population. Available phosphorus is soil P that can be dissolved in water and citric acid. The form of P in the soil can be distinguished based on its solubility and availability in the soil, water-soluble P is the form of P that can be absorbed by plants.

Based on the results of the analysis of variance at a significance level of 5%, there was no interaction between the concentration and dosage treatments of nutrient solutions on phosphorus availability. This is suspected to be due to the binding of phosphorus with Al and Fe in the soil, as stated by Rahmayuni, et al. (2023), who noted that the Inceptisols contain clay (which includes Al and Fe) ranging from 21.7% to 36.6%, which can bind phosphorus. Additionally, the population of phosphate-solubilizing bacteria is thought to be affected by the application of nutrient solutions, which may lead to an abundance of nutrients, thereby causing phosphate-solubilizing bacteria to lack energy sources for proliferation (Pan and Cai, 2023). The independent effect of concentration in the nutrient solution treatment significantly influenced the population of phosphate-solubilizing bacteria.

Table 1. The effect of nutrient solutions on phosphorus availability and the population of phosphate-solubilizing bacteria.

Treatments	Phosphate Availability (ppm)	PSB population (x 10^7 CFU g^{-1})
Nutrient Solution Concentrations		
1200 ppm	24.10	29.72 a
1600 ppm	28.16	50.06 b
2000 ppm	31.64	60.72 b
Nutrient Solution Doses		
200 mL	27.89	38.22
400 mL	26.49	55.89
600 mL	29.52	46.39

Note: Numbers marked with the same letter indicate no significant difference based on the Duncan's Multiple Range Test at a significance level of 5%.

Based on Table 1, the treatment of nutrient solution concentration increases the phosphorus availability in the soil, although it does not have a significant effect. The nutrient solution concentration at each level is directly proportional to the increase in phosphorus availability in the soil, rising from 1200 ppm to 1.600 ppm (16.7%) and further increasing at 2000 ppm (12.3%). The dosage of the nutrient solution also non-significantly increased available P in the soil from 200 mL to 400 mL (5%), but decreased at 600 mL (11.4%). In the initial soil analysis, available P in the Inceptisols of Jatinangor was only 1.04 ppm P. The independent effects of nutrient solution concentration and dosage increased available P in the soil, but did not show significant differences. This is suspected to be due to the Inceptisols' inability to retain phosphorus effectively, leading to leaching of the nutrient, consistent with Ginting, et al. (2024), who stated that Inceptisols have low nutrient retention capacity.

The treatment of nutrient solution concentration significantly increased the population of phosphate-solubilizing bacteria (PSB) in the soil, particularly at a concentration of 2000 ppm. However, this increase was not statistically different from the treatment at 1600 ppm. In the initial soil analysis, the population of PSB in Jatinangor Inceptisols was recorded at 36 x 10^7 CFU mL^{-1}. The nutrient solution concentration raised the PSB population from 1200 ppm to 1600 ppm (68.4%), and further increased at 2000 ppm (21.3%). The rise in PSB population is believed to be due to the presence of micronutrients and Fe-EDTA in the nutrient solution, which act as cofactors in the formation of phosphatase enzymes by PSB. This is consistent with the statement by Vigani and Murgia (2018) that iron can serve as a cofactor in enzymatic reactions involving PSB, thus contributing to the increase in PSB populations.

The application of nutrient solution doses did not significantly increase the population of phosphate-solubilizing bacteria (PSB) from a dose of 200 mL to 400 mL by 46.3%, but it decreased by 17% at a dose of 600 mL. This decline is suspected to be due to the high nutrient solution dose providing excessive nutrients, which may lead to insufficient energy sources for the PSB to proliferate. The growth of PSB can accelerate when they receive the necessary materials for their development. The addition of enriched biochar containing a mixture of dolomite and guano can enhance the population of PSB by increasing organic carbon content (Lai et al, 2022).

Dry Weight of Plant and Phosphorus Uptake. Based on the analysis of variance at a significance level of 5%, it was shown that there was no interaction between the concentration and dose treatments of the nutrient solution on the dry weight of the plants and phosphorus uptake. This is suspected to be because the nutrient supply from the nutrient solution was less than what was needed to release potential phosphorus (Johan et al., 2021), resulting in suboptimal plant growth during the vegetative phase. The independent effects of the concentration and dose treatments of the nutrient solution significantly influenced both the dry weight of the plants and phosphorus uptake.

Based on the data in Table 2, the treatment of nutrient solution concentration significantly increased the dry weight of the plants at a concentration of 1200 ppm, but there was no significant difference compared to the concentration of 1600 ppm. The dry weight of the plants decreased by 1.1 g (4.08%) from 1200 ppm to 1600 ppm, and decreased by 10.5 g (40%) from 1600 ppm to 2000 ppm. The application of nutrient solution doses increased the dry weight non-significantly by 2.2 g from a dose of 400 mL to 600 mL (9.91%). The significant decrease in dry weight at higher concentrations of the nutrient solution and the non-significant differences in dry weight due to the doses are suspected to be because the plants were unable to absorb excessive nutrients. Therefore, nutrient application during the vegetative phase tends to be more beneficial at lower concentrations of the nutrient solution. Plant growth, especially during the vegetative phase, is greatly influenced by the availability of nutrients and water, but it is also affected by the plant's ability to absorb them (Francis et al., 2023). Fertilization with nutrient solutions containing nitrogen can increase the number of leaves and leaf area in plants, which ultimately can enhance the dry weight of the plants.

Table 2. The effect of nutrient solutions on dry weight of plant and phosphorus uptake on eight weeks after plant.

Treatments	Dry Weight (g)	P Uptake (mg $Plant^{-1}$)	P Content (%)
Nutrient Solution Concentrations			
1200 ppm	27.22 b	80.81 ab	0.35
1600 ppm	26.11 b	103.41 b	0.43
2000 ppm	15.56 a	53.59 a	0.30
Nutrient Solution Doses			
200 mL	22.22	86.40	0.41
400 mL	22.22	68.27	0.32
600 mL	24.44	83.14	0.36

Note: Numbers marked with the same letter indicate no significant difference based on the Duncan's Multiple Range Test at a significance level of 5%.

The treatment of nutrient solution concentration significantly increased phosphorus uptake at a concentration of 1600 ppm, but there was no significant difference compared to the concentration of 1200 ppm. Phosphorus uptake increased by 27% from 1200 ppm to 1600 ppm and then decreased by 48% from 1600 ppm to 2000 ppm. This decline is suspected to be due to the plants' ability to absorb nutrients in small to moderate amounts, limited by their capacity for nutrient uptake (Alaoui et al., 2022). The application of nutrient solution doses decreased phosphorus uptake by 18.2 g from a dose of 200 mL to 400 mL but increased by 14.9 g at a dose of 600 mL. The phosphorus content obtained from the analysis did not show significant differences due to either the concentration or the doses of the nutrient solution.

The lack of significant effect of nutrient solution doses on phosphorus uptake and phosphorus content in plants is suspected to be due to a substantial amount of phosphorus being bound, which prevents optimal phosphorus uptake by the plants. The release of phosphorus by phosphate-solubilizing bacteria (PSB) greatly influences the availability of phosphorus in the soil, as well as its absorption by plants. The amount of phosphorus absorbed by plants is directly proportional to the dry weight of the plants, with phosphorus playing a crucial role in enhancing root growth, allowing plants to absorb more nutrients. This improved nutrient uptake contributes to better plant growth and increased biomass. Takahashi and Katoh, (2022) state that the contact between plant roots and phosphorus, along with the distribution of plant roots, significantly affects phosphorus uptake and the dry weight of the plants.

Chili Plant Growth. Based on the analysis of variance at a significance level of 5%, there was no interaction between the concentration and dose treatments of the nutrient solution on the number of leaves in chili plants. This is suspected by the vegetative phase, the plants were unable to absorb nitrogen effectively to significantly increase the leaf count. The independent effect of the dose treatment of the nutrient solution had a significant impact on the number of leaves at two WAP (weeks after planting).

Table 3. The effect of nutrient solutions on number of leaves.

Treatments	Number of Leaves		
	2 WAP	4 WAP	6 WAP
Nutrient Solution Concentrations			
1200 ppm	9,83	13.17	60.50
1600 ppm	9.50	15.00	75.44
2000 ppm	10.39	13.78	66.39
Nutrient Solution Doses			
200 mL	9.50 a	14.83	75.22
400 mL	9.67 ab	12.83	63.11
600 mL	10.56 b	14.27	64.00

Note: Numbers marked with the same letter indicate no significant difference based on the Duncan's Multiple Range Test at a significance level of 5%.

In Table 3, the best treatment concentration of the nutrient solution for increasing the number of leaves non-significantly was found at a concentration of 1200 ppm at two WAP, while the best treatment was at a concentration of 1.600 ppm at four and six WAP. This is suspected to be because, during the vegetative phase, the plants did not have the ability to absorb nutrients in abundance, resulting in excess nutrients not being absorbed by the plants. This aligns with the statement by Francis, et al. (2023) that plants in the vegetative phase have limitations in nutrient absorption from the soil.

At two WAP, the treatment of nutrient solution at a dose of 600 mL had a significantly different effect, but there was no significant difference compared to the 400 mL dose treatment. The best treatment for increasing the number of leaves in the plants was found at a dose of 200 mL, although this increase was not statistically significant. The lack of significant effect from the nutrient solution doses on the number of leaves at four and six WAP is suspected to be due to Inceptisols soil's inability to retain excess nutrients from the applied nutrient solution doses, which aligns with the statement by Ginting, et al. (2024) that Inceptisols have a low capacity to retain nutrients. Various nutrient components in the nutrient solution, such as nitrogen, phosphorus, potassium, magnesium, and others, can enhance the number of leaves in chili plants. The provision of nutrients during the vegetative phase, especially nitrogen, is capable of promoting plant growth and development, particularly in leaf formation (Rutkowski and Łysiak, 2023).

Table 4. The effect of nutrient solutions on plant height and stem diameter.

Treatments	Plant height (cm)			Stem diameter (cm)		
	2 WAP	4 WAP	6 WAP	2 WAP	4 WAP	6 WAP
Nutrient Solution Concentrations						
1200 ppm	15.74	25.85	47.39	2.09	4.34	5.76
1600 ppm	15.75	27.54	53.25	1.90	4.70	6.64
2000 ppm	15.38	27.54	51.39	2.06	4.68	6.37
Nutrient Solution Doses						
200 mL	15,42	27.70	54.72	1.98	4.59	6.65
400 mL	16,08	26.64	47.58	2.12	4.60	5.77
600 mL	15,37	26.59	49.72	1.95	4.52	6.34

Based on the results of the analysis of variance at a significance level of 5%, there was no interaction between the concentration and dose treatments of the nutrient solution on plant height and stem diameter in chili plants. This is suspected to be due to the nutrient solution suppressing the population of phosphate-solubilizing bacteria in the soil, thereby preventing the maximization of phosphorus availability in the soil (Pan and Cai, 2023). The concentration and dose treatments of the nutrient solution did not have a significant impact on plant height and stem diameter in chili plants.

The concentration of the nutrient solution at 1.600 ppm resulted in the highest plant height and stem diameter in chili plants at six WAP, although there was no significant difference compared to other nutrient solution concentrations. The lack of significant effect from the nutrient solution concentration on plant height and stem diameter is suspected to be due to poor physical, chemical, and biological properties of the soil, which hinder optimal plant development. Ezeokoli, et al. (2023) state that the addition of organic matter to the soil can improve soil health and quality, as well as increase the population of beneficial microorganisms in the soil.

Based on Table 7, the dose of nutrient solution at 200 mL achieved the highest results for plant height and stem diameter at six WAP, although there was no significant difference compared to other nutrient solution doses. The lack of significant effect from the nutrient solution doses on plant height and stem diameter in chili plants is suspected to be due to the plants not effectively absorbing macronutrients, resulting in suboptimal growth in height and stem diameter. Nitrogen, as an essential nutrient, plays a crucial role in plant growth during the vegetative phase (Leghari et al., 2016). Potassium promotes cell enlargement and elongation, which contributes to greater stem girth and height in plants (Bulawa et al.., 2022)

Yield of Chili Plants (Number and Weight of Fruits each Plant). Based on the analysis of variance at a significance level of 5%, there is an interaction between the concentration and dosage treatments of the nutrient solution on the number of chili fruits each plant.

The nutrient solution with a concentration of 2.000 ppm and a dosage of 600 mL produced the highest number of fruits per chili plant compared to other treatments, with an average of 44.67 fruits each plant (Table 5). The increase in nutrient solution concentration at 2000 ppm at each dosage level raised the average number of fruits per plant. Similarly, increasing the dosage of the nutrient solution to 600 mL at each concentration level also enhanced the average number of fruits per plant.

Table 5. The effect of nutrient solutions on number of chili fruits each plant.

Nutrient Solution Concentrates	**Nutrient Solution Doses**		
	200 mL	**400 mL**	**600 mL**
1200 ppm	13.67 a A	21.67 a A	18.33 a A
1600 ppm	18.00 a A	22.33 a A	27.67 a A
2000 ppm	23.33 a A	26.00 a A	44.67 b B

Notes: average values followed by the same letter are not significantly different according to Duncan's Multiple Range Test at a significance level of 0.05. Lowercase letters are read vertically, comparing the three concentrations at the same dosage, while uppercase letters are read horizontally, comparing the three dosages at the same concentration.

Table 6. The effect of nutrient solutions on weight of chili fruits each plant.

Nutrient Solution Concentrations	Nutrient Solution Doses		
	200 mL	400 mL	600 mL
1200 ppm	343.33 a A	449.33 a A	510.67 a A
1600 ppm	531.67 a A	501.00 a A	308.00 a A
2000 ppm	366.33 a A	405.33 a A	725.53 b B

Notes: average values followed by the same letter are not significantly different according to Duncan's Multiple Range Test at a significance level of 0.05. Lowercase letters are read vertically, comparing the three concentrations at the same dosage, while uppercase letters are read horizontally, comparing the three dosages at the same concentration.

The application of nutrient solution concentrations and dosages that provide various macro and micronutrients is believed to assist plants in the fruit formation process. Phosphorus plays a role in cell division and photosynthesis, while potassium helps distribute energy from the leaves to the fruits. Adequate availability of these two nutrients is expected to increase both the number and weight of fruits on the plants Kakar et al., 2024).

ISSN: 1412-4718, eISSN: 2581-138x

Based on the analysis of variance at a significance level of 5%, there is an interaction between the concentration and dosage treatments of the nutrient solution on the weight of chili fruits each plant.

The treatment with a concentration of 2000 ppm and a dosage of 600 mL produced the highest fruit weight per chili plant compared to other treatments, amounting to 725.53 g per plant (Table 6). The increase in nutrient solution concentration at 2000 ppm at each dosage level raised the average fruit weight per plant. Similarly, increasing the dosage of the nutrient solution to 600 mL at each concentration level also enhanced the average fruit weight per plant.

As with the number of fruits, the amount of nutrient solution applied is directly proportional to the weight of the fruits per plant. The fulfillment of nitrogen nutrients through the concentration and dosage treatments of the nutrient solution is believed to help increase the number of leaves on the plants, allowing them to capture more energy for photosynthesis. Phosphorus and potassium contribute to root growth, enzyme activity, and photosynthesis, and their existence is expected to enhance both the weight and number of fruits produced by the plants (Akram et al., 2017).

Yield Quality (*Grading*). Based on the results of the variance analysis at a significance level of 5%, there is an interaction between the treatment of concentration and dosage of nutrient solution on the quality of grade A chili yields.

Table 7. The effect of nutrient solutions on quality of grade A chili yields.

Nutrient Solution Concentrations	Nutrient Solution Doses 200 mL	400 mL	600 mL
1200 ppm	5.00 a A	8.67 a A	8.67 a A
1600 ppm	9.00 a A	12.67 a A	8.67 a A
2000 ppm	10.67 a A	13.33 a A	24.33 b B

Notes: average values followed by the same letter are not significantly different according to Duncan's Multiple Range Test at a significance level of 0.05. Lowercase letters are read vertically, comparing the three concentrations at the same dosage, while uppercase letters are read horizontally, comparing the three dosages at the same concentration.

Based on Table 7, the interaction of a concentration of 2.000 ppm and a dosage of 600 mL of nutrient solution significantly increases the yield of grade A chili peppers. The treatment with a concentration of 2.000 ppm and a dosage of 600 mL is the best treatment for producing the highest number of grade A fruits, with an average yield of 24.33 fruits. The fulfillment of both macro and micronutrients is believed to enhance the production yield of chili plants, in line with the research by Ahmed, et al. (2024), which states that micronutrients are essential for the promotion of plant growth and the optimization of yields in horticultural systems, thus potentially improving the fruit grade as well. The total number of grade A fruits is 303, which is more than those with grade B and C.

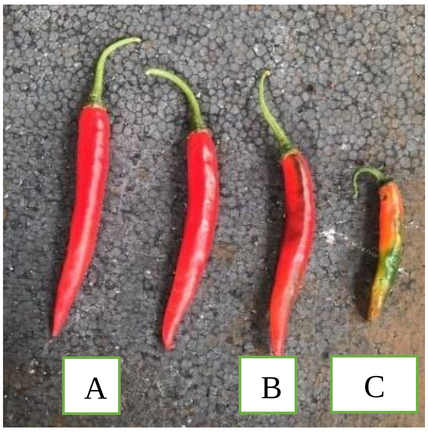

Figure 1. Chili fruit grades.

Phosphorus (P) plays a significant role in root development, flowering, and fruit ripening, which means that an increase in the number of flowers can enhance the potential yield of fruits in plants. Akram, et al. (2017) stated that adequate fulfillment of P and potassium (K) in plants can improve flower growth, positively affecting both the quantity and weight of chili fruits. The availability of nitrogen and potassium that can be absorbed by plants can yield good results, with nitrogen promoting healthy vegetative growth, particularly in stems and leaves, while potassium maintains the plant's metabolism effectively.

Based on the results of the variance analysis at a significance level of 5%, there is no interaction between the concentration and dosage treatments of the nutrient solution on the yield of grade B chili yields. This is suspected to be because the nutrients from the nutrient solution have been directed towards producing better fruit grade (grade A). The independent effects of concentration and dosage in the nutrient solution treatment significantly influence the quality of grade B chili pepper yields.

Table 8. The effect of nutrient solutions on the quality of grade B chili yields.

Treatments	Yield Quality (Grade B)
Nutrient Solution Concentrations	
1200 ppm	7.33 a
1600 ppm	8.89 ab
2000 ppm	11.89 b
Nutrient Solution Doses	
200 mL	6.78 a
400 mL	10.33 b
600 mL	11.00 b

Note: Numbers marked with the same letter indicate no significant difference based on the Duncan's Multiple Range Test at a significance level of 5%.

Based on Table 8, the treatment with a concentration of 2000 ppm of the nutrient solution significantly increases the yield of grade B chili peppers, although it does not differ significantly from the concentration of 1600 ppm. Table 10 shows that there is an independent interaction from the nutrient solution concentration treatment. As the concentration of the nutrient solution increases, the number of grade B chili peppers produced also increases. The best concentration for producing the highest number of grade B fruits is 2000 ppm, with an average yield of 11.89 grade B fruits however, this does not differ significantly from the concentration of 1.600 ppm, which has an average yield of 8,89 grade B fruits. The suspected increase in grade B chili yields due to the concentration of the nutrient solution is attributed to the fulfillment of nutritional needs during the vegetative phase, which can enhance root expansion for more optimal nutrient absorption. This aligns with research conducted by Takahashi and Katoh (2022), which indicates that a wider root distribution allows plants to reach a larger area, making nutrient absorption more efficient.

As the dosage of the nutrient solution increases, the number of grade B chili peppers produced also increases. The best dosage for producing the highest number of grade B fruits is 600 mL, with an average yield of 11.00 grade B fruits however, this does not differ significantly from the dosage of 400 mL, which has an average yield of 10,33 grade B fruits. The increase in grade B chili yields is directly proportional to the increase in the dosage of the nutrient solution, which is believed to be due to the fulfillment of the plant's nutritional needs. This is in line with research by Akram (2017), which states that abundant availability of phosphorus and potassium can enhance the weight of plant fruits.

Based on the results of the variance analysis at a significance level of 5%, it shows that there is no interaction between the concentration and dosage treatments of the nutrient solution on the quality of grade C chili yields. This is suspected to be due to pest and disease attacks that damage the physiological condition of the fruits, leading to a degradation in fruit quality. The independent effects of applying concentration and dosage of the nutrient solution do not significantly influence the quality of grade C plant yields.

Table 9. The quality of grade C chili yields.

Treatments	Yield Quality (Grade C)
Nutrient Solution Concentrations	
1200 ppm	3.11
1600 ppm	3.67
2000 ppm	3.33
Nutrient Solution Doses	
200 mL	3.33
400 mL	3.22
600 mL	3.55

The suspected cause of damage to the fruits, which results in them being classified as grade C, is plant pests. The attack from these pests can reduce the fruit's weight and create physical defects. The fruit fly is one of the pests that can attack chili fruits by puncturing them to lay their eggs. When the eggs hatch, the larvae feed on the fruit, causing it to lose weight, rot quickly, and eventually drop off. In addition to fruit flies, a common disease affecting chili plants is anthracnose. This disease is caused by the fungus Colletotrichum sp., and symptoms include small, round, dark brownish spots that are watery on the fruit. If these spots expand, they can lead to rot.

Conclusion

The concentration and dosage of the nutrient solution significantly affect the number of fruits each plant, fruit weight each plant, and the quality of grade A chili yields. However, they do not significantly influence phosphorus availability, population of phosphate-solubilizing bacteria, dry weight of the plants, phosphorus uptake, number of leaves, plant height, stem diameter, or the quality of grade B

ISSN: 1412-4718, eISSN: 2581-138x

and C chili yields. The independent effects of nutrient solution concentration significantly impact the population of phosphate-solubilizing bacteria, dry weight of the plants, phosphorus uptake, and grade B chili yields. The independent effects of nutrient solution dosage significantly influence the growth in the number of leaves and grade B chili yields. A concentration and dosage of 2000 ppm + 600 mL can be an alternative fertilization method for cultivating red chili plants in soil media in polybags. Further research is needed regarding soil health indices such as pH and organic carbon.

Acknowledgments

We express our deepest gratitude to the BRIN house project for funding this research and Nicky Octavia, SP., MP. as the lead researcher of this project.

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