The application of response surface method in producing water spinach (Ipomoea reptans Poir) through hydroponics technique with iron-electrode electrolyzed water

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Abstract: This study aimed to determine the influence of Electrolyzed water on the growth of water spinach viewed from the dry weight, plant height, number of leaves, and stem circumferences factors. This research had been conducted using a hydroponic technique with iron-electrode electrolysis water as the treatment. The method used was regression analysis, both linear and quadratic. The optimizations of the treatments were seen using the surface response method. The results showed a significant effect on the length of electrolysis duration on dry weight, the number of leaves, plant height, and stem circumference. The most significant models were the model with the explanatory variables of electrolysis duration and the number of leaves. This result indicated the addition of Electrolyzed water with an iron diode increased the number of leaves’ stomata which affected the dry weight.

Keywords: Electrolysis, Hydroponic, Regression, Response surface method, Water-spinach

1. Introduction

Hydroponics is a futuristic technique developed as an alternative to planting growth on infertile soils[1]. The hydroponic method is a planting technique that utilizes water without soil [2]. The nutrition for the hydroponic plants can use environmentally friendly media that contain the same or more significant amounts of vitamins and minerals compared to products grown in the field [3]. A well-maintained planting system can increase crop production [4,5]. In a hydroponic system, almost all aspects of the environment, air, and roots around plants can be controlled. A good quality hydroponic system depends on light for its growth and development. Hydroponic systems are being studied extensively, especially regarding the nutritional needs of hydroponic plants [6,7].

Quality seeds used in hydroponic cultivation are also one of the main factors in the success of hydroponic experiments [8]. The sterilization of instruments, seeds, and culture media is also essential in reducing the risk of contamination and providing a good start for plants before being transferred to a series of hydroponic systems. The hydroponic system offers a more homogeneous nutrient medium for plants and less risk of diseases transmitted through the soil [9].

One of the essential micro-minerals for water spinach is iron (Fe) [10]. Iron is a crucial element for living organisms, especially plants. Iron has a vital role in cell respiration, intermediate metabolism, oxygen transportation, DNA stability, and photosynthesis. About 30% of the world’s land is made up of alkaline soils, which cause less iron demand for plants’ growth[11]. The addition of Fe as much as...
six ppm in Anthurium Hookeri can increase the height, stem length, the number of leaves because Fe has a role in the formation of chlorophyll so that the more Fe in plants, the more active the photosynthetic activity [12,13]. The process of photosynthesis will produce food and energy sources for plant growth and development. Hydroponic plants are also influenced by the pH of the water in the hydroponic system[14,15]. Electrolyzed water can occur over an extended operating temperature range with different pH [16].

Electrolyzed water is the decomposition of water compounds (H2O) using an electric current to produce oxygen (O2) and hydrogen (H2). Electrolysis of water using iron electrodes had been applied to hydroponic plants that required observation of plant height, wet weight, the number of leaves, and stem circumference to see the differences. The growth of hydroponic water spinach with electrolysis electrolyzed water was better than without electrolysis treatment [17].

The application of the mathematical model of the response surface method had been carried out in this study for modeling and analysis of nutrient optimization on the growth of hydroponic water spinach[18]. The response surface method(RSM) is an essential statistical and mathematical design used to determine the effect of various factors on the desired response. The RSM method is inferior to other methods because this method takes a long time. RSM can also be used based on different experimental designs [19]. An optimum design is generally considered the model that best meets the standards of research. Usually, there is a neutral procedure that can be calculated from the variables and determine the optimum pattern. The physics procedure in this research was used to analyze possible trends to determine the best or optimum design [20]. This research aimed to determine the effect of the electrolyzed water using iron electrodes on the dry weight of water spinach. The dry weight is influenced by stem circumference, plant height, and the number of leaves so that in this research, it was necessary to investigate the effect of electrolyzed water with iron-electrode on stem circumference, plant height, and the number of leaves.

2. Method
The materials used in this research were water spinach seeds, electrolyzed water with an iron cathode, and NPK (Nitrogen, Phosphor, and Kalium). The tools used in this study were water pumps, hydroponic installations, hoses, hacksaw, cuter (knives), drills, buckets, pH meters, TDS meters, Rockwool, seeding containers, flannelette, rulers, and scales. The flowchart of the research stages is shown in Figure 1 and the hydroponic installation with the addition of the electrolyzed water is shown in Figure 2.

The measurements were made to determine the effect of iron ions on the growth circumference of the stem, plant height, number of leaves, and dry weight. The method used was the response surface method. It is the combination of statistical and mathematical techniques for conducting experimental designs, building models, evaluating the influence of factors, and finding the optimum conditions of the factors that affect responses. The response surface method had been used to get optimal results. This research also employed a mathematical equation, namely regression analysis. The regression analysis was used to find the relationship between the response of Y and X factors through the linear and quadratic regression model. Variables observed were plant height, stem circumference, number of leaves, and dry weight treated with electrolysis duration as an explanatory variable.
The steps of mathematical modeling in this research are:

1. Model all variables using regression analysis using the full model:
   \[ \hat{y} = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 \]  
   (1)
Description:
\( x_1 \): The number of leaves
\( x_2 \): Plant height
\( x_3 \): Circumference of the stem
\( x_4 \): Electrolysis duration
\( y \): Dry weight.

2. Use linear and quadratic regressions to explain the response variable.
   a. Finding the best model through Analysis of Variance (ANOVA).
   b. Make a surface response plot of the best model to find the optimum value of the treatment while using a smoothing method to fit the plot first.

3. Use the smoothing method of the thin-plate spleen with the following equation:
   \[
   \hat{\mu}(t) = \beta_0 + \beta_1 t + \sum_{k=1}^{K} u_k C(\|t - \kappa_k\|)
   \]
   (2)
   Where \( \beta = (\beta_0, \beta_{11}, \beta_{12}, u_1, ..., u_K) \) is the vector of parameters and \( \kappa_1 < \cdots < \kappa_K \) are knots in \( \mathbb{R}^2 \).
   \( \|r\| = \|t - \kappa_k\| \) is the distance between \( t \) and knot \( \kappa_k \) [21].
   This research was assisted by Minitab software and R program version 4.0.2.

3. Results and Discussion
   The mathematical models obtained in the regression analysis are as follows:
   \[
   \hat{y} = -0.993 + 0.02806 x_1 + 0.0277 x_2 + 0.358 x_3 + 0.00161 x_4
   \]
   (3)
   \[
   \hat{y} = -0.974 + 0.03175 x_1 + 0.05351 x_2 + 0.00255 x_4
   \]
   (4)
   \[
   \hat{y} = -0.778 + 0.02453 x_1 + 0.6220 x_3 + 0.00236 x_4
   \]
   (5)
   \[
   \hat{y} = 0.441 + 0.0267 x_1 + 0.01143 x_4
   \]
   (6)
   When viewed in backward elimination, the best model of all the equations above was equation (6) because it produced the smallest p-value to all estimators with a significant coefficient. The significance value of the model can be seen from the ANOVA test result in Table 3.1. while the significance test of the parameter estimator coefficients can be seen in table 3.2.

| Source           | DF | Adj SS  | Adj MS  | F-Value | P-Value |
|------------------|----|---------|---------|---------|---------|
| Regression       | 2  | 12.7036 | 6.35182 | 168.91  | 0.000   |
| Leaves           | 1  | 0.1957  | 0.19571 | 5.20    | 0.028   |
| Electrolysis duration | 1 | 1.1363  | 1.13635 | 30.22   | 0.000   |
| Error            | 37 | 1.3914  | 0.03760 |         |         |
| Total            | 39 | 14.0950 |         |         |         |
Table 2. The Result of the Test of Significance Coefficient

| Term                | Coef  | SE Coef | T-Value | p-Value |
|---------------------|-------|---------|---------|---------|
| Constant            | 0.441 | 0.161   | 2.74    | 0.009   |
| Leaves              | 0.0267| 0.0117  | 2.28    | 0.028   |
| Electrolysis duration | 0.01143 | 0.00208 | 5.50    | 0.000   |

Based on Table 1 and Table 2, it can be concluded that the regression equation produced good results while all the coefficient predictors were significantly different. The positive values on the coefficient value indicated that the longer the electrolysis duration and the more the number of leaves, the more significant the dry weight of water spinach. Of all the variables, it turned out that electrolysis was directly proportional to the leaves to increase the plant's weight. This indicated the significant influence of the electrolyzed water with an iron electrode on the number of leaves.

The bucket where the electrolysis process took place was separated by a salt bridge so that when the anode emits iron ions \( (Fe^{2+}) \), it did not react with the \( OH^- \) generated at the cathode. The following is the reaction at the anode is [22,23]:

\[
Fe \rightarrow [Fe]^{2+} + 2e^- 
\]

The electrolyzed water flowed into hydroponic water spinach. The roots absorbed the iron ions then distributed them into the leaves [24]. The iron ions in the leaves assisted the process of photosynthesis [25]. In this research, it was seen that the longer time of the electrolysis process, the more the number of leaves. Thus, proving that the iron ions produced from the cathode can increase the number of leaves because the process of photosynthesis occurred in the leaves. Stem circumference and plant height did not show significant differences. The iron ions helped the process of photosynthesis by flowing into the leaves and stimulating the leaf growth.

![Figure 3. The Regression Plot of the Electrolysis duration on Dry Weight](image)

The relationship between electrolysis duration and dry weight is shown in Figure 3. The quadratic relationship was better than the linear relationship with a coefficient of determination \( R^2 \) of 90.4%. Based on the figure, it can also be concluded that the duration of electrolysis had an optimum limit. In other words, the electrolysis duration did not always increase.
In contrast to figure 3, the relationship between weight and the number of leaves indicated a linear relationship towards infinity. Figure 4 indicated that the more leaves, the heavier the dry weight. It proved that iron ion and water electrolysis – NPK (Nitrogen Phosphor and Kalium) had more effect on the number of leaves in increasing the dry weight.

The form of the relationship between electrolysis duration and the number of leaves showed a quadratic relationship. This form indicated that the longer the electrolysis duration, the more leaves grew. It is worth remembering that the relationship was not linear so that there was a limit of the electrolysis duration.
After smoothing all the variables, the shape of the response surface graph can be illustrated. In Figure 6, the overall form of the relationship of all variables can be seen. It can be concluded the respective associations of the variables indicated that the longer the electrolysis duration, the more weight and the number of leaves of the water spinach can be produced. Based on the graph, the optimum value of the interaction between variables was 80-120 minutes as the best electrolysis duration.

4. Conclusion and Suggestion
From the overall explanatory variables, it can be concluded that the variable that showed the most significant influence was the electrolysis duration variable and the number of leaves to explain the dry weight of water spinach. The relationships were non-linear relationships so that there were limits to the variables' magnitude, especially the electrolysis duration. Further research needs to be done to see the optimum electrolysis duration because the electrolysis duration in this research was no more than 120 minutes. Other variables need to be added that might explain the weight variables of water spinach, especially the hydroponic plants.

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Figure 6. The Response Surface Plot of the Number of Leaves, Electrolysis Duration, and Dry Weight
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