

A Water Spinach Hydroponic System Using Automatic Water Temperature and pH Level Controllers

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Abstract— Hydroponics is a water-based planting method that uses less extensive land while enabling us to produce healthier and more hygienic plants. For water spinach (*Ipomoea aquatica*), the hydroponic system must be able to maintain the water temperature within 26°C-29°C and the pH level between 5.5 and 6.5. Due to these strict requirements, the hydroponic system for water spinach must be continuously monitored to remain within the desired ranges. One solution to automatically control the water temperature and pH level utilizes a control system that incorporates several components such as the Arduino Mega 2560, the SEN0161 pH sensor, the DS18B20 waterproof sensor, a water heater, a fan, and a peristaltic pump. The benefits of using the control system for the water spinach hydroponic system were evaluated against the conventional no-controller method by assessing the growth of the water spinach. With the controller, the water spinaches had an average height and average number of leaves per plant of 24 cm and 53, respectively. These averages are significantly larger than those measured from the conventional method which yielded 16 cm average height and 16 leaves per plant.

Index Terms— Hydroponics, Smart farming, Control system, Arduino Mega 2560.

I. INTRODUCTION

THE Water spinach (*Ipomoea aquatica*) is a commonly found semi-aquatic, tropical plant in Southeast Asia grown as a vegetable for its tender shoots. Water spinach is a powerhouse of nutrients that offer many benefits due to its rich contents of water, iron, and vitamin A. It has been known to provide an anti-inflammatory diet which can also calm nerves, prevent diabetes, and fight liver damage [1][2].

With the increasing public awareness of the importance of nutrition for health, the demand for vegetables including water spinach and their production have also been on the rise. However, the production could be potentially improved with

the proper use of technology, not just to meet the rising demand but also to further develop water spinach as an agribusiness that will bring substantial benefits to farmers.

One effective method for water spinach cultivation is to use the hydroponic technology. This is a method of cultivating plants by utilizing water without needing soil as a planting medium. The water used, however, must be continuously monitored and adjusted in terms of its temperature and degree of acidity (pH) so that the water spinach can grow properly [3]-[5].

Water temperature is an important parameter due to its effect on the oxygen absorbed by plants. When the water temperature is too high, the dissolved oxygen absorbed by plant roots will decrease, the heat will then inhibit the content of chlorophyll further causing a decrease in photosynthetic efficiency. On the other hand, if the temperature is too low, it will damage the plant's enzymes. In addition, if the plant is subjected to low temperature, it will also cause a decrease in the conductance of the hydraulic roots [6]-[8].

Research indicates that water spinach does not grow well in environments where the mean temperature falls below 24°C [9]. The temperatures ranging from 25°C to 35°C are generally favorable for its development. These temperatures promote not only vegetative growth but also enhance the plant's ability to absorb nutrients and water efficiently [10]. Based on a previous study on aquaponic temperature control study of water spinach using fuzzy logic control, water spinach typically requires water temperature of 25°C–30°C, with the preferred range of 25°C–27°C, in order to get better water spinach growth results.

The pH level is another factor that greatly affects plant growth. The pH level of the nutrient solution is very susceptible to change due to the imbalance of anions and cations absorbed by plants which are continuously streamed with water. The optimal pH range for most hydroponically grown plants is typically between 5.5 and 6.5, as this range maximizes nutrient availability and uptake [11]. If the pH of the solution in plants is less (acidic), it will be difficult for plants to absorb nutrients such as calcium, magnesium, and phosphorus in the solution [12][13]. When the pH of the solution is excessive (alkaline), it will be difficult for plants to absorb nutrients such as copper, manganese, zinc, and iron. As a result, plants will experience nutrient deficiencies or grow stunted and cannot produce optimally [14].

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Despite the importance of water temperature and pH level for growing water spinach, farmers are currently still manually monitoring the plants regularly to ensure that the water spinach solution remains within the desired temperature and pH level. Such a labor intensive and tedious task could be avoided by utilizing a control system that can automatically perform the same task to regulate the water's temperature and pH level.

II. HYDROPONIC NUTRIENT FILM TECHNIQUE

The study entails the construction of two water spinach hydroponic systems. The first is a conventional system with manual monitoring of water temperature and pH level. The other has the same setup except for the addition of a control system that will automatically regulate the water temperature and pH level. The two systems were concurrently operated and growth data of the plants were observed, collected, compared, and then analyzed. Both systems employ the Hydroponic Nutrient Film Technique (NFT) method. The method was selected to enable water circulation throughout the plant where the water will flow by the plant roots; thus, preventing soaking of plant roots.

The first system operates with a conventional method which consists of a solution storage tank and pipes as a growing medium for hydroponic plants. The second system consists of a solution storage tank, pipes as a growing medium for hydroponic plants, and a controller device. A mini water pump is placed in the holding tank to force the water cycle flowing in the growth pipe so that the solution can flow and hit the roots of hydroponic plants. This growth pipe is made at an angle of about 3-5 cm following the NFT system. Furthermore, five plant holes are provided as illustrated in Figure 1. In addition, placed within the holding tank is a waterproof DS18B20 temperature sensor and an actuator to control the water temperature. The actuator uses a 12V 80°C heater plate heating element to raise the water temperature and a 12V DC fan to lower the water temperature. The installed pH control includes a hose input flow that functions to flow pH UP and pH DOWN, a pH sensor, and a stirrer that mixes up the solution in the tub. The solution hose is of silicone type which aims to prevent the solution from being affected by the chemical properties of acidic or alkaline solutions. The hose diameter was calculated to fit the output size of the peristaltic pump used. The system design is shown in Fig. 1.

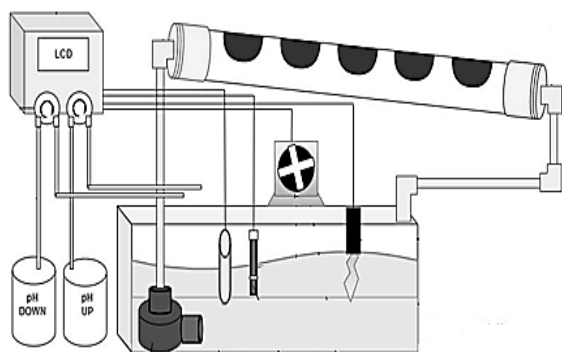


Fig. 1. NFT Hydroponic System Design



Fig. 2. The actual NFT Hydroponic System

The working principle of the constructed system is based on a solution containing nutrients placed into the two holding tanks according to what is needed by the water spinach. The attached sensor will then detect the temperature and the pH level of the solution whose values will be displayed on an LCD. Whenever the water temperature is detected below 26°C, the water heater will be activated until the water temperature rises to 28°C. However, if the detected temperature is above 29°C then the fan will turn on until the water temperature reaches 28°C. Lastly, when the temperature is between 25°C and 29°C, the actuator will remain inactivated and the temperature control has been completed. In addition, if the solution has a pH level that is less than the setpoint, the motor driver will operate the peristaltic pump 1 which will consequently release the pH UP solution. Conversely, if the detected pH level is greater than the setpoint, the motor driver will operate the peristaltic pump 2 which will release the pH DOWN solution. The peristaltic pump for the solution will continue to work until the solution value in the holding tank is in accordance with the setpoint. PID controller is utilized to improve the performance of the actuator.

III. RESULT AND DISCUSSION

A. Control System Testing

Tests were performed to verify the functionality of the water spinach hydroponic system with the controller. In particular, measurements were obtained to evaluate and assess the effectiveness of the controller in adjusting the water temperature and pH level.

The controller employs the PID method and therefore experiments were carried out to determine the appropriate values for the PID gains K_p , K_i , and K_d . The proportional gain value (K_p) was adjusted to obtain quick temperature rise for heating the water. The value $K_p = 155$ was found to produce reasonably fast response time while having small percent overshoot. For the integral gain K_i , the value that yields a small percent error with respect to the temperature setpoint is $K_i = 0.000001$. The derivative gain K_d for the water temperature controller turned out to be unnecessary as the appropriate response of the system had been achieved.

For the pH control, the PID method was also utilized to

achieve the speed (RPM) of the peristaltic pump. Further experiments were conducted to fine tune and determine PID gain values. The results indicated that the gain values $K_p = 140.55$, $K_i = 142.90$ and $K_d = 0.41$ produce a system response whose rise time is 0.0268 seconds, settling time is 0.0706 seconds, and percent overshoot is 3.06.

Once the PID gains were acquired for both the water temperature and pH level controllers, more tests were performed on the hydroponic system to again verify the operation and functionality of the controller. The Arduino IDE software application was used to test the system directly. Since the required setpoint value of water spinach is 5.5–6.5, the setpoint value entered was 6 with a tolerance value of ± 0.5 . Furthermore, to increase or decrease the pH level by 1 pH value, a 100-150mL of pH solution is needed in 6 liters of solution in the holding tanks.

B. Temperature and pH Reading Test

Temperature control tests were carried out over four days with measurements taken twice a day. Tests for controlling the pH levels were conducted on the first day of installation with measurement intervals of several hours. Test results demonstrated that the controlled hydroponic system was able to maintain the water temperature within the desired temperature range. On the contrary, the water temperature of the uncontrolled hydroponic system fluctuated above or below the set temperature. Similarly, the controlled hydroponic system was able to keep the pH level in the solution tank close to the pH setpoint, while the uncontrolled hydroponic system had pH level that remained almost at the same level. Summaries of the test results on the water temperature and pH level are shown in Table I and Table II respectively.

TABLE I
TEST RESULTS OF THE TEMPERATURE CONTROL SYSTEM

Day	Time (UTC+7)	Water Temperature (°C)	
		Uncontrolled Tank	Controlled Tank
1	10.00 a.m.	25.3	27.8
	02.00 p.m.	26.3	27.9
2	10.00 a.m.	25.1	27.1
	02.00 p.m.	29.5	29.0
3	10.00 a.m.	26.3	28.0
	02.00 p.m.	27.3	27.9
4	10.00 a.m.	25.8	27.8
	02.00 p.m.	29.4	29.0

TABLE 2
TEST RESULTS OF THE pH CONTROL SYSTEM

No.	Time (UTC+7)	Initial pH level	Time (UTC+7)	Final pH level
1	09.00 a.m.	7.51	09.10 a.m.	6.12
2	12.00 p.m.	7.63	12.10 p.m.	6.05
3	03.00 p.m.	7.26	03.10 p.m.	5.95
4	06.00 p.m.	7.21	06.10 p.m.	5.84

C. Water Spinach Growth

To evaluate the effectiveness of using the controller in the water spinach hydroponic system, stem height and number of leaves of the water spinach in each net pot from the growth pipe were measured and then compared with those obtained from the conventional system. Results from the measurements were plotted in Figures 3 and 4 which show the average graph of the height of the stem and the number of leaves of the water spinach. The graphs indicate that the water spinach that grew with the temperature and pH control devices has better growth compared to those that come from the conventional system that lacks the controller. This further proves that the temperature value and pH level in the solution have indeed a significant effect on the growth of water spinach.

One cause of the poor growth results of the water spinach that came from the conventional hydroponic system is due to the uncontrolled pH in the solution tank. Solutions in holding tank without pH control can turn acidic because of several factors such as the respiration process in plants which releases carbon dioxide which produces carbonic acid making the pH level in the solution more acidic. Furthermore, the solution in the holding tank may also become alkaline due to the photosynthetic process of plants which produces oxygen by absorbing water from the roots and carbon from the air. In addition, when the water temperature is below optimal, the nutrient uptake by the water spinach may be hampered because plant roots could freeze depriving plants of oxygen. This will result in disruption of the respiration process which is the process of oxygen entering and releasing carbon dioxide. Lastly, having water temperature above the optimum will also cause a major issue due to the unstable water absorption and poor transpiration by the water spinach, further causing the water spinach to wilt.

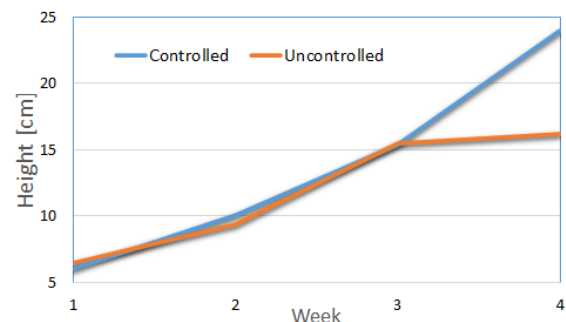


Fig. 3. Average height of the stem

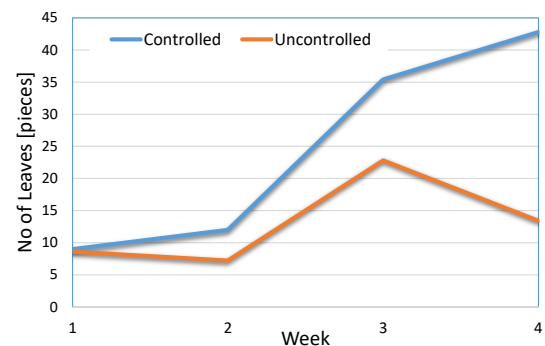


Fig. 4. Average number of the stem

IV. CONCLUSION

The study presented in this paper involves the use of water temperature and pH level controllers in a hydroponic system for water spinach. The controller utilizes sensors which enable the system to maintain the desired set of water temperature and pH level. More specifically, the water temperature and pH level controllers using the DS18B20 waterproof temperature sensor and the SEN0161 pH sensor in conjunction with Arduino Mega 2560-based NFT hydroponic method have been proven to be effective in improving the quality of the produced water spinach compared to those obtained from the conventional hydroponic system.

A 12V DC heater plate was utilized to raise the water temperature and a fan to lower the water temperature. The operation of the heater plate is controlled by PID whose gain values are $K_p=155$; $K_i=0.000001$ and $K_d=1$. The pH Down and pH Up solutions were delivered to the holding tank using a peristaltic pump controlled also by PID whose gain values are $K_p = 140.55$; $K_i=142.90$; and $K_d = 0.41$. With the controller operating as intended, the controlled water spinach hydroponic system produced water spinaches whose average stem height is 24 cm and number of leaves of 53 pieces. These are improvements when compared to water spinaches from the conventional system which have an average stem height of 16.2 cm and the number of leaves of 16 pieces.

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REFERENCES

- [1] M. H. Ibrahim, N. A. Abas, and S. M. Zahra, “Impact of Salinity Stress on Germination of Water Spinach (*Ipomoea aquatica*),” *Annals of Research and Review in Biology*, vol. 31, no. 5, pp. 1–12, Apr. 2019.
- [2] R. Fevria, S. Aliciafarma, Vauzia, and Edwin, “Comparison of Nutritional Content of Water Spinach (*Ipomoea aquatica*) Cultivated Hydroponically and Non-Hydroponically,” in *Journal of Physics: Conference Series*, Institute of Physics, Jun. 2021, doi: 10.1088/1742-6596/1940/1/012049.
- [3] A. U. A. Syed et al., “Comparative Assessment of Hydroponic and Geoponic Cultivation Systems for Sustainable Spinach Cultivation,” *Pakistan Journal of Agricultural Research*, vol. 34, no. 4, pp. 678–688, 2021, doi: 10.17582/journal.pjar/2021/34.4.678.688.
- [4] C. V. Nanda and M. N. Khozin, “Cultivation of Water Spinach Using a Hydroponic System at Different AB Mix Concentrations,” *Journal of Sustainable Agriculture (JSA)*, vol. 1, no. 1, pp. 1–6, Sep. 2022.
- [5] I. Safir and A. Nurza, “Cultivation of Water Spinach (*Ipomoea reptans* Poir) Production by Using DFT and NFT,” *Journal of Social Research (JOSR)*, vol. 1, no. 10, pp. 1110–1115, 2022. [Online]. Available: <http://ijsr.internationaljournalallabs.com/index.php/ijsr>.
- [6] D. Thakulla, B. Dunn, B. Hu, C. Goad, and N. Maness, “Nutrient Solution Temperature Affects Growth and Brix Parameters of Seventeen Lettuce Cultivars Grown in an NFT Hydroponic System,” *Horticulturae*, vol. 7, no. 9, Sep. 2021, doi: 10.3390/horticulturae7090321.
- [7] D. P. Kumarathunge et al., “The Temperature Optima for Tree Seedling Photosynthesis and Growth Depend on Water Inputs,” *Global Change Biology*, vol. 26, no. 4, pp. 2544–2560, Apr. 2020, doi: 10.1111/gcb.14975.
- [8] M. Sakamoto and T. Suzuki, “Effect of Root-Zone Temperature on Growth and Quality of Hydroponically Grown Red Leaf Lettuce (*Lactuca sativa* L. cv. Red Wave),” *American Journal of Plant Sciences*, vol. 6, no. 14, pp. 2350–2360, 2015, doi: 10.4236/ajps.2015.614238.
- [9] A. Gothberg, G. Gothberg, M. Greger, and B.-E. Bengtsson, “Accumulation of Heavy Metals in Water Spinach (*Ipomoea aquatica*) Cultivated in the Bangkok Region, Thailand,” *Environmental Toxicology and Chemistry*, vol. 21, no. 9, pp. 1934–1939, 2002.
- [10] R. E. R. M. Yusufirashim, M. H. Ibrahim, C. A. C. Abdullah, and A. A. Izad, “Growth, Photosynthesis and Quality of Water Spinach (*Ipomoea aquatica*) as Influenced by Magnetic Nanoparticles (MNP) Application,” *Annals of Research and Review in Biology*, vol. 31, no. 6, pp. 1–15, May 2019.
- [11] I. S. Nasution et al., “Embedded Fuzzy Logic for Controlling pH and Nutrition in Hydroponic Cultivation,” in *IOP Conference Series: Earth and Environmental Science*, Institute of Physics, 2023, doi: 10.1088/1755-1315/1183/1/012113.
- [12] D. P. Gillespie, C. Kubota, and S. A. Miller, “Effects of Low pH of Hydroponic Nutrient Solution on Plant Growth, Nutrient Uptake, and Root Rot Disease Incidence of Basil (*Ocimum basilicum* L.),” *HortScience*, vol. 55, no. 8, pp. 1251–1258, Jun. 2020, doi: 10.21273/HORTSCI14986-20.
- [13] D. P. Gillespie, G. Papio, and C. Kubota, “High Nutrient Concentrations of Hydroponic Solution Can Improve Growth and Nutrient Uptake of Spinach (*Spinacia oleracea* L.) Grown in Acidic Nutrient Solution,” *HortScience*, vol. 56, no. 6, pp. 687–694, Jun. 2021, doi: 10.21273/HORTSCI15777-21.
- [14] A. J. Turner, C. I. Arzola, and G. H. Nunez, “High pH Stress Affects Root Morphology and Nutritional Status of Hydroponically Grown Rhododendron (*Rhododendron* spp.),” *Plants*, vol. 9, no. 8, pp. 1–12, Aug. 2020, doi: 10.3390/plants9081019.