P-ISSN 2382-4583 E-ISSN 2964-3648

International Journal of Agricultural Research and Educational Management
Vol. 8 No. 2 (June, 2025) | pp 43-52
Available online at https://iigdpublishers.com/journals/27

Open Access | Original Article

A Comparative Study of Growth Parameters for Leafy Vegetables Cultivated in Soil and Hydroponic Systems

[1]Labya Prabhas & [2]Amia Ekka

School of Studies in Life Science, Pt. Ravishankar Shukla University, Raipur, India.

Keywords
Growth Parameter, Green Leafy Vegetables, Hydroponics, Soil, Seed Initiation Time, Seed Viability Ratio.

Volume 8 | Issue 2
June, 2025

P-ISSN 2382-4583
E-ISSN 2964-3648

Abstract

This study investigates several preliminary growth parameters in seven species of edible green leafy vegetables, a popular source of dietary components in Asian countries like India, China, Sri Lanka, and Bangladesh, focusing on hydroponics, an innovative technique that reduces productivity costs in developing countries and pharmaceutical industries. Controlling climate factors had a positive impact on plant survival and growth. Using LEDs, automated temperature control units, and humidity was found to be crucial in the hydroponic system. This study focused on seed initiation time and seed viability ratio as preliminary growth parameters. The study found that seed initiation time (SIT) in soil-based and hydroponic cultivation systems was earliest in C. arietinum (3 days), followed by A. viridis L. (6 days), C. olitorious L. (7 days), T. feonum-graecum L., S. oleracea L. (9 days), C. sativum L. (11 days), and M. arvensis L. (15 days). In this study on a total of 900 seeds for different plant species, it was found that hydroponics had a higher percentage viability ratio for leafy vegetables, with M. arvensis having almost doubled the viability rate in hydroponics, influenced by indoor facilities and environmental parameters. The overall impact of hydroponics was significant over the preliminary growth parameters in seven different edible green leafy plants.

INTRODUCTION

Nutrition is crucial for living organisms, and agriculture faces challenges in India due to high population density, growing demand, climate, and seasonal dependency (Jarapala, 2017). Green leafy vegetables are popular for their essential and medicinal values, and regular consumption helps avoid micronutrient deficiencies and diseases like vision problems, skin health, cardiovascular disease, and hormonal imbalance. Greens are a significant dietary component in Asian countries like India, China, Sri Lanka, and Bangladesh. Climate and geographical conditions, such as global warming and seasonal dependency, make it difficult for humans to survive. Advanced techniques and understanding plant species' nutritional requirements can help develop effective strategies. Environmental factors like air, water, light, humidity, and temperature also play a role (Jerusha et al., 2021; Das et al., 2022).

In Chhattisgarh (India), tribal people rely on agriculture for their livelihood and nutritional needs. Leafy vegetables are healthy, easily available sources of vitamins, minerals, carbohydrates, amino acids, and proteins (Kumari, 2020; Shukla et al., 2022). They also have therapeutic value and secondary metabolites that provide disease cures. Hydroponics is an innovative technique that reduces productivity costs by producing a large number of vegetables. Despite its popularity among farmers in India, it is not widely adopted. Hydroponics is increasingly recognized for its effectiveness in cultivating herbs and plant species in developing countries like India, Bangladesh, Pakistan, and Sri Lanka. It can be practiced indoors or outdoors and can be used for indoor greenhouses (Kratky et al., 1988; Albaho et al., 2008; Guo et al., 2019; Maiti et al., 2020).

MATERIALS AND METHODS

Selection of Leafy Plants

The study analyzed seven leafy vegetables, Amaranthus viridis L., Trigonella foenum-graecum L., Chorchorus olitorius L., Coriandrum sativum L., Mentha arvensis L., Cicer arietinum L., and Spinacia oleracea L., grown in a hydroponic system and soil for comparative analysis. Standardized seeds were purchased from local markets and sown in December and May as per seasonal availability in local markets. Growth responses, including seed initiation time (SIT) and seed viability ratio (SVR), were systematically analyzed (Chauhan et al., 2014; Vandam et al., 2017; Prabhas et al., 2017).

Hydroponic System

Design and Setup Establishment

The Ebb and Flow flood and drain systems are popular among home hydroponic growers due to their ease of construction, cost-effectiveness, and adaptability. These systems flood plant root systems with nutritional solutions, using a timer to pump water through tubing from a reservoir. The overflow tube sets water levels and prevents spillage. The system can be built using various household materials and can be modified based on plant size, temperature, humidity, and medium (Lee et al., 2019; Mamatha et al., 2023). The system involves flooding a growing tray with nutrient solution and draining it back into the reservoir using a submerged pump with a timer. The frequency of the timer's use depends on plant type, size, temperature, humidity, and growing medium. The Ebb and Flow System modifies its nutritional solution according to plant size, temperature, humidity, and medium by momentarily flooding a grow tray with it using a submersible pump and then draining it back into the reservoir (Harsha et al., 2018; Jan et al., 2020; Jangilwad et al., 2020).

Nutrient Medium

Plant growth relies on sunlight and water, with nutrient solutions providing major and micro elements. Macronutrients include potassium, phosphorus, nitrogen, calcium, magnesium, and sulfur, while micronutrients include iron, chlorine, manganese, boron, copper, nickel, and molybdenum (HwiAhn et al., 2023). Supplements like cobalt, selenium, silicon, iodine, sodium, and vanadium may also be beneficial. Careful selection of optimum concentrations of micro- and macro-elements is crucial for optimal plant growth and metabolic activities. A broad-spectrum nutrient medium is beneficial (Choi et al., 2005; Ferguson et al., 2014; Currey et al., 2019; Gillespie et al., 2021).

Table 1: Showing broad range nutrient solution (Jones, 2014)

Major Elements			Micronutrient		
Element	Ionic form	Concentration Range mg/L, ppm	Element	Ionic form	Concentration Range mg/L, ppm
Nitrogen (N)	NO_3^-, NH_4^+	100 – 200	Boron (B)	BO_3^{3-}	0.03
Phosphorus (P)	HPO_4^{2-}, $H_2PO_4^-$	15 - 30	Chlorine (Cl)	Cl^-	-
Potassium (K)	K^+	100 – 200	Copper (Cu)	Cu^{2+}	0.01 – 0.10
Calcium (Ca)	Ca^{2+}	200 – 300	Iron (Fe)	Fe^{2+}, Fe^{3+}	2 – 12
Magnesium (Mg)	Mg^{2+}	30 – 80	Manganese (Mn)	Mn^{2+}	0.5 – 2.0
Sulfur (S)	SO_4^{2-}	70 - 150	Molybdenum (Mo)	$Mo0_4^-$	0.05
			Zinc (Zn)	Zn^{2+}	0.05 – 0.50

Control over Climatic Factors

Climate change impacts temperature, light intensity, and relative humidity, which are crucial for plant survival and growth. The most beneficial light spectrum for plant growth is red (600–800 nm) and blue (380–480 nm). Temperature and rainfall are also important factors for agricultural productivity. Optimal temperature ranges from 10°C to 35°C for most plant species, enhancing physiological and biochemical changes (Ferreira et al., 2018; Diwan et al., 2021; Tadevosyan et al., 2023).

Measurement and Analysis of Various Growth Parameters in Soil-Based Cultivars and Hydroponics

Time Period of Seedling Initiation

After sowing seed in the soil, seed germination occurs through rupturing of the seed coat, and the first visual appearance of the seedling coming out of the soil was noted and counted manually in 3 different quadrates to maintain replicas for each species. Hence, a total of 21 plus quadrates were established and maintained throughout the study for each leafy vegetable plant species in both soil and hydroponic systems (Dube et al., 2021). Simultaneously, seeds were also sown in a hydroponic system. Time was recorded for seed initiation based on physical observation of sown seeds at a particular time interval. Important characteristics that are important for the observation of seed initiation time are listed below:

Rupturing of seed coat.
Appearance of foliage.

Different plant species may show different seed initiation times. Hence, regular monitoring at a particular time interval is required.

Seed Viability Ratio in both Soil and Hydroponic Systems Per Unit Time

A total of 100 seeds are used per square foot (quadrate) for both systems. A total of nine quadrates were established for cultivating each leafy plant species to maintain replicas. (Lee et al., 2021).

$$\text{Seed Viability Ratio} = \frac{\text{Total number of seeds sown in all quadrates}}{\text{Total number of seedlings appeared after time interval}}$$

RESULT AND DISCUSSION

Seed Initiation Time (SIT)

Seed initiation was examined through the clear appearance of rupturing of the seed coat, recorded in the time required (in the number of days) for rupturing of the seed coat (Kader, 2005; Bhadra et al., 2024). This was visible to the naked eye. In soil-based seed sown, the first appearance of seed initiation was recorded earliest in C. arietinum (3 days), followed by A. viridis L. (6 days), C. olitorious L. (7 days), T. foenum- graecum L., S. oleracea L. (9 days), C. sativum L. (11 days), and M. arvensis L. (15 days). M. arvensis L. has taken the longest time period of 15 days to show the first appearance of seed initiation. M. arvensis L. required a large amount of water per day (Table 2 and Figure 1).

On the other hand, the first appearance of seed initiation in hydroponics was recorded earliest in C. arietinum L. (2 days), similar to the soilless technique. Secondly, A. viridis L. was observed for seed initiation 5 days after the seed was sown. C. olitorious L. and S. oleracea L. took 6 days, followed by both T. foenum-graecum L. and C. sativum L. (9 days). Lastly, seed initiation was recorded in M. arvensis L. (11 days) in hydroponics, comparable to soil-based cultivation. In this experiment, the seed initiation sequence in both soil-based cultivation and hydroponic systems was almost similar. Although, the hydroponic system showed more positive support for A. viridis L., C. olitorious L., C. sativum L., M. arvensis L., and S. oleracea L. (Tables 2 and Figure 1).

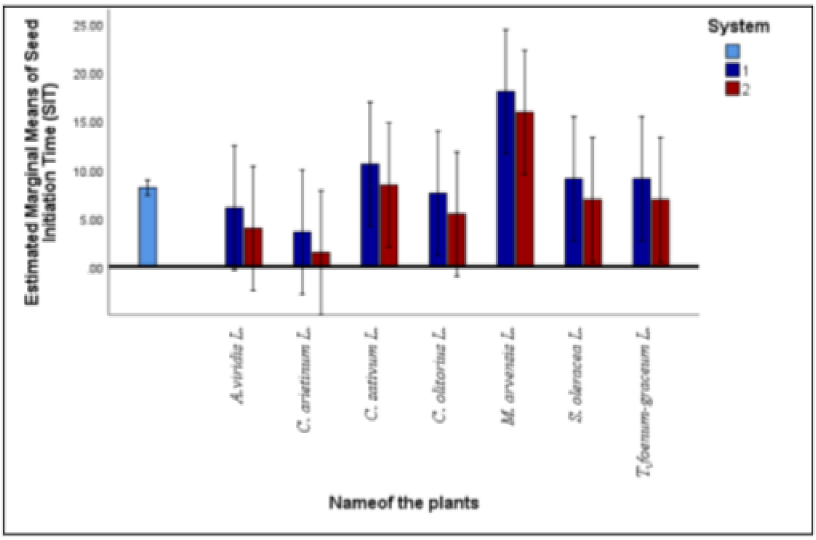
The results showed that seed initiation time varies among plant species and is influenced by factors such as seed coat thickness, nutrient absorption, and soil moisture availability. Water softens the seed coat, allowing embryos to rupture easily. Temperature variations can delay seed coat rupturing. Hydroponics provides consistent water supply and moisture support, while a humid environment outside the indoor system may reduce seed initiation time (Yadav et al., 2023).

Table 2: Assessment of seed initiation in seven different plant species in soil and hydroponic system per unit time.

S. No.	Name of the plant	Common Name	Total no. of seed sown in soil and hydroponics (Number of seed per 1 ft^2 area) x Average of 9 quadrates	Average no. of days for seed initiation in Soil (No. of Days) ± SD	Average no. of days for seed initiation In Hydroponics (No. of Days) ± SD
1	*A. viridis* L.	Chaulai bhaji		6 ± 0.50	5 ± 0.60
2	*T. f. graceum* L.	Methi bhaji		9 ± 0.78	9 ± 0.92
3	*C. olitorius* L.	Chech bhaji		7 ± 0.70	6 ± 0.70
4	*C. sativum* L.	Dhaniya	100 x 9 = 900	11 ± 0.60	9 ± 0.50
5	*M. arvensis* L.	Mint / Pudina		19 ± 0.86	12 ± 0.70
6	*C. arietinum* L.	Chana bhaji		2 ± 0.70	2 ± 0.00
7	*S. oleracea* L.	Palak bhaji		9 ± 0.50	6 ± 0.92
Mean ± average SD				9.14 ± 0.66	7.00 ± 0.62
SD and Standard Error				5.04 and 1.90	3.26 and 1.23

*Area = 1 $feet^2$

Figure 1: Showing seed initiation time after seed sown in soil (SSS) and hydroponics (SSH) of selected leafy vegetables.



Seed Viability Ratio (SVR)

A total of 900 seeds were sown in nine quadrates, both in soil and hydroponics. Viability was observed through the clear appearance of rupturing of the seed coat and the appearance of seedlings coming out of the seed coat (Fantinatti and Usberti, 2007; Kanmege et al., 2016). Percent viability was recorded between seed sown in soil (SSS) and seed sown in hydroponics (SSH). Percent viability in A. viridis L. (37% in SSS and 66% in SSH), T.F. graceum L. (45% in SSS and 73% in SSH), C. olitorious L. (56% in SSS and 81% in SSH), C. sativum L. (75% in SSS and 92% in SSH), M. arvensis L. (41% in SSS and 83% in SSH), C. arietinum L. (77% in SSS and 80% in SSH), and S. oleracea L. (81% in SSS and 87% in SSH). The seed viability percent ratio was higher in hydroponics for all leafy vegetables. A significant difference was recorded between seed sown in soil and seed sown in hydroponics. M. arvensis showed a significant difference between SSS and SSH; the viability rate was almost double in hydroponics (Tables 2 and 3). Numerous other factors support the efficacy and appropriateness of hydroponic farming for the cultivation of tiny leafy vegetables. In a hydroponic system, seed viability was unquestionably higher than in a soil-based growth method. More protection for seeds is offered by indoor facilities against insects and animals that feed on seeds (Yadav et al., 2023). Furthermore, variations in common environmental parameters such as temperature, moisture content, and soil texture can impact the rate of seed viability in all plant species (Tables 3 and Figure 2).

Table 3: Assessment of seed viability analysis for seven different plant species in soil and hydroponics per unit area.

Name of the plants	Mean values for sample's reading in 9 quadrates	
	Soil	Hydroponics
A. Viridis L.	37 ± 3.10	66 ± 2.73
T. foenum-greacum	45 ±2.51	73 ± 0.78
C. olitorius L.	55 ± 1.51	81 ± 1.24
C. sativum L.	75 ± 2.57	92 ± 1.44
M. arvensis L.	40 ± 2.21	83 ± 2.08
C. arietinum L.	77 ± 3.02	80 ± 1.36
S. oleracea L.	81 ± 1.60	87 ± 1.73

*Area = 1 feet^2 (Size of one quadrate)

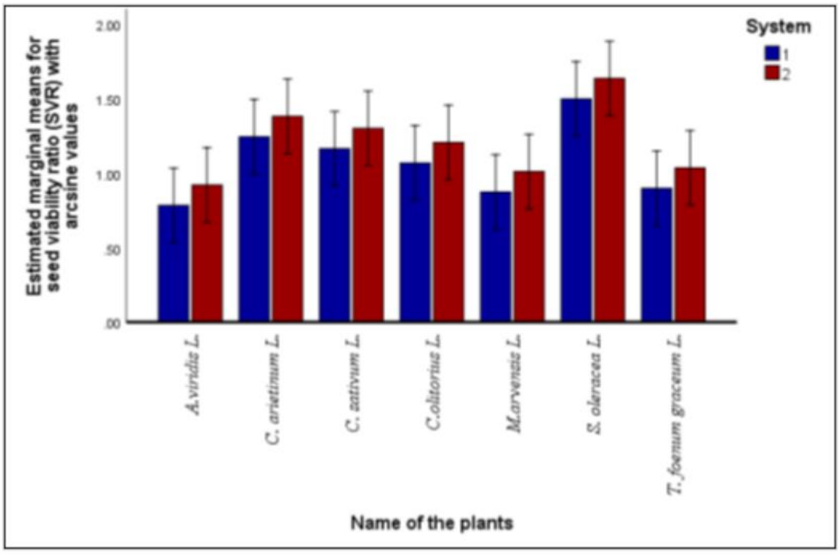


Figure 2: Showing seed viability percentage recorded after seed sown in soil (SSS) and hydroponics (SSH) of selected leafy vegetables.

Statistical Analysis

Experimental measurements were performed. The obtained data is analyzed and expressed as the average ± standard deviation for the number of plants in a total of nine quadrates (Table 3). The magnitude of the means, standard curve, standard errors, and standard deviations were calculated using SPSS software 24.0. Descriptive analysis of the data obtained for seed viability ratio (SVR) values obtained for soil and hydroponics is shown in tables 4 and 5 separately.

Seed Initiation Time (SIT)

In order to compare the data and analyze LAI in two distinct independent production systems (soil and hydroponic), significant values at the 95% confidence level were tested with a t-test. First, Levi's test and the normalcy assumptions were verified. There was no significant difference in scores for soil (M = 9.14, SD = 5.69) and hydroponics (M = 7.0, SD = 3.55); t (12) =.844, p =.561. As the p > 0.05, the null hypothesis is accepted (Table 4).

Table 4: Showing results of t-test of leafy vegetables for seed initiation time (SIT) in Soil and Hydroponics

Independent Samples Test										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Seed Initiation Time	Equal variances assumed	.358	.561	.844	12	.415	2.14286	2.53948	-3.390	7.67592
	Equal variances not assumed			.844	10.06	.418	2.14286	2.53948	-3.510	7.79643

Table 5: Showing results of t-test of leafy vegetables for Seed Viability Ratio (SVR) in Soil and Hydroponics

Independent Samples Test										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Seed viability ratio (SVR)	Equal variances assumed	4.502	.055	-.961	12	.355	-.13714	.14267	-.44799	.17370
	Equal variances not assumed			-.961	9.840	.359	-.13714	.14267	-.45573	.18144

Seed Viability Ratio (SVR)

In order to compare the data and analyze SVR in two distinct independent production systems (soil and hydroponic), significant values at the 95% confidence level were tested with a t-test. First, Levi's test and the normalcy assumptions were verified. There is a significant difference in scores for soil (M = 1.07, SD =.32) and hydroponics (M = 1.21, SD = 0.19); t (12) = -.961, p = 0.05. As the p value is equal to 0.05, the null hypothesis is rejected (Table 5).

CONCLUSION

A comparative analysis has been conducted between hydroponic systems and soil-based plant cultivation methods. It was found that seed initiation occurs when the seed coat ruptures, causing sprouting. The experiment began with the selection of healthy seed from a stock of seven plant species, including C. arietinum L., A. viridis L., C. olitorious L., T. foenum-graecum L., S. oleracea L., C. sativum L., and M. arvensis L. Seeds were sown in soil and a hydroponics system simultaneously. Hydroponics readings showed more support for the preliminary growth parameters, such as seed initiation time. The experimentation was continued for a seed viability ratio check also. This phase of research revealed that hydroponics had a higher percentage of seed viability ratios for leafy vegetables, with M. arvensis L. having almost doubled the viability rate in hydroponics, influenced by indoor facilities and environmental parameters.

ACKNOWLEDGEMENT

I am appreciative and lucky to have Dr. Megha Agrawal, Assistant Professor at Gurukul Mahila Mahavidyalaya in Kalibadi Raipur, provide me with ongoing support, encouragement, and advice. I am grateful to Dr. P.A. Khan for his technical assistance. I would want to express my profound appreciation to all those who have participated in this research project.

REFERENCES

Albaho M., Thomas B., Christopher A. Evaluation of hydroponic techniques on growth and productivity of greenhouse grown bell pepper and strawberry. International journal of vegetable science. 2008; 14(1): 23-40. https://doi.org/10.1080/19315260801890492.

Adelmann T. The easy grow bed for any of your plants. What is a Hydroponic Ebb-Flow System? Assessed on 12.6.2024 https://hydroplanner.com/blog/ebb-flow-system 2023; Accessed on 12.07.2022.

Amagloh F. K., Atuna R.A., McBride R., Carey E. E., Christides, T. Nutrient and total polyphenol contents of dark green leafy vegetables, and estimation of their iron bioaccessibility using the In Vitro digestion/Caco-2 cell model. Foods. 2017; 6(54): 1-12. https://doi.org/10.3390/foods6070054.

Ann smreciu and kimberly gould wild rose consulting, inc. Seed viability, germination and longevity of selected boreal species: a literature review. prepared for cosia (osvc), retrieved from https://www.cclmportal.ca/sites/default/files/2020. 2017; Accessed on 12.07.2024

Arasaretnam S., Kiruthika A., Mahendran T. Nutritional and mineral composition of selected green leafy vegetables. Ceylon journal of science. 2014; 47(1): 35-41. DOI: 10.4038/cjs.v47i1.7484.

Bhadra M., Mondal S., Das A., Bandyopadhyay A. Gibberellic acid treatment improves seed germination and seedling establishment in Tinospora cordifolia (Willd.) Hook. F. and Thoms, Journal of applied biology and biotechnology. 2014; 12(4): 128-135. DOI:10.7324/JABB.2024.158607

Chauhan D., Shrivastava A. K., Patra S. Diversity of leafy vegetables used by tribal peoples of Chhattisgarh, India. International journal of current microbiology and applied sciences. 2014; 3(4): 611-622.

Choi K. Y., Yang E-Y., Park D-K., Kim Y. C., Seo T. C., Yun H. K., Seo H. D. Development of nutrient solution for hydroponics of cruciferae leaf vegetables based on nutrient-water absorption rate and the cation ratio. Journal of Bio-Environment control. 2005; 14(4): 289-297.

Currey C. J., Walters K. J., Flac N. Nutrient solution strength does not interact with the daily light integral to affect hydroponic cilantro, dill and parsley growth and tissue mineral nutrient concentration. Agronomy. 2019; 9(389): 1-14. https://doi.org/10.3390/agronomy9070389.

Das S., Goswami M., Yadav R. N. S., Bandyopadhyay T. Quantitative estimation of terpenoid content in some tea cultivars of north east India and their In Vitro cell cultures using an optimized spectrophotometric method. Journal of advanced scientific research. 2022; 13(3): 112-117. https://doi.org/10.55218/JASR.202213318.

Diwan P., Naik R. K., Gautam A. Studies on the status and opportunity of leafy vegetable crop harvesting in Chhattisgarh. Biological forum – An international journal. 2021; 13(4): 837-841.

Dube P., Struik P. C. Seed germination and morphological character of traditional leafy vegetables. African journal of agricultural research. 2021; 17(4): 598-603. DOI: 10.5897/AJAR2018.13173

Fantinatti J. B., Usberti R. Seed viability constants for Eucalyptus grandis", Pesq. Agropec.

Bras. Brasilia. 2014; 42(1): 111-117. https://doi.org/10.1590/S0100-204X2007000100015.

Ferguson S. D., Saliga R. P., Omaye, S. T. Investigating the effects of hydroponic media on quality of greenhouse grown leafy greens. International journal of agricultrual extension. 2014; 2(3): 227-234.

Ferreira J. F. S., Sandhu D., Liu X., Halvorson J. J. Spinach (Spinacea oleracea L.) Response to salinity nutritional value, physiological parameters, antioxidant capacity, and gene expression. Agriculture. 2018; 163(8): 1-17. DOI: 10.3390/agriculture8100163.

Gillespie D. P., Papio G., Kubota C. High nutrient concentrations of hydroponic solution can improve growth and nutrient uptake of spinach (Spinacia oleracea L.) grown in acidic nutrient solution. HortScience. 2021; 56(6): 687-694. DOI: https://doi.org/10.21273/HORTSCI15777-21

Guo J., Yan Y., Dong L., Jiao Y., Xiong H., Tian L. S. Y., Yang Y., Shi A. Quality control technique and related factors for hydroponic leafy vegetables. HortScience. 2019; 54(8): 1330-1337. DOI: 10.21273/HORTSCI13853-18.

Harsha A., Deekshith K., Murali Krishna B. K., Sachin K. T., Sushanth N. Automated hydroponics greenhouse monitoring system using adafruit.io controlled by google assistant. International journal of engineering research & technology. 2018; 6(15): 1-4. DOI: 10.17577/IJERTCONV6IS15030.

HwiAhn Y., Noh S. W., Kim S. J., Park J. S. Selection of appropriate nutrient solution for simultaneous hydroponics of three leafy vegetables (Brassicaceae). Korean journal of agricultural science. 2018; 49(3): 643-653. 10.7744/KJOAS.20220058.

Jan S., Rashid Z., Ahngar T. A., Iqbal S., Naikoo M. A., Majeed S., Bhat T. A., Gul R., Nazir I. Hydroponic – A review. International journal of current microbiology and applied sciences. 2020; 9(8): 1779-1787. https://doi.org/10.20546/ijcmas.2020.908.206.

Jangilwad M. D., Chandel A. C. Hydroponics as an advanced technique for vegetable production. Just agriculture. 2020; 1(3): 1-4.

Jarapala S. R. Nutrition science in India: green leafy vegetables: A potent food source to alleviate micronutrient deficiencies. International research journal of basic and applied sciences. 2017; 2(1): 7-13.

Jerusha S., Anand A. V., Adarsh J., Chandra K. K. R., Vishnu S. B. K. Organic hydroponic farming incorporated with recycles water. Journal of physics: conferences series 1916. 2021; 1-5. 10.1088/1742-6596/1916/1/012105.

Jones J. B. Complete guide for growing plants hydroponically. CRC Press Taylor & Francis Group 6000 Broken Sound Parkway NW, Suite 300 Boca Raton, FL 33487-2742. 2014.

Kader M. A. A Comparison of Seed Germination Calculation Formulae and the Associated Interpretation of Resulting Data. Journal and proceedings of the royal society of new south wales. 2005; 138: 65-75. DOI:10.5962/p.361564.

Kanmege G., Anouma'a M., Fotso, Mboubda H. D., Omokolo D. N. Germination and sensitivity to desiccation of Cola anomala (K. Schum.) seeds. Fruits. 2016; 71(2): 87-92. DOI: 10.1051/fruits/2015051.

Kratky B. A., Bowen J. E. Observation on a noncirculating hydroponic system for Tomato Production. HortScience. 1988; 23(5): 906-097. DOI: 10.21273/HORTSCI.23.5.906

Kumari P, Role of carbohydrates in nutrition. International journal of advanced research in science, communication and technology. 2020; 9(2): 160-164.

Lee D-H., Kim J-D. Comparative study on growth of leafy vegetables grown in a hybrid BFT-aquaponics using Japanese eel, Anguilla japonica and hydroponics. 2021; 24(7): 260-275. https://doi.org/10.47853/FAS.2021.e26

Lee D-H., Kim J-Y., Lim S-R., Kim D-Y., Kim K-B., Kim J-M., Kim J-D. Comparative study on growth and yield of far eastern catfish Silurus asotus and leafy vegetables grown in hybrid BFT-aquaponics, semi-RAS and hydroponics. Fish aquatic science. 2019; 52(5): 482-495.

Maiti M., Saha T. Understanding hydroponics and its scope in India. Just agriculture. 2020. 1(2): 281-288.

Mamatha V., Kavitha J. C. Machine learning based crop growth management in greenhouse environment using hydroponics farming technique. Measurement: Sensors. 2023; 25 (100665): 1-7. https://doi.org/10.1016/j.measen.2023.100665.

Prabhas L. Agrawal M., Shukla, K. Study on practicability of hydroponical culture with some leafy vegetables known for medicinal properties in Chhattisgarh – India. International journal of advance research in science and engineering. 2017; 6(11): 1395-1406.

Prabhas L., Ekka A. Total chlorophyll determination in leafy vegetables cultivated in hydroponics and soil. International journal of food and nutritional sciences. 2022; 11(2): 1584-1592.

Shukla P., Meghani S., Charmi P., Dhrumi S., Rathod R. Z., Saraf S. M. A review on qualitative and quantitative analysis of carbohydrates extracted from bacteria. Acta scientific pharmaceutical sciences. 2022; 6(3): 20-28.

Tadevosyan A., Hakobjanyan A., Tovmasyan A., Astryan A., Roosta H. R., Daryadar M. Hypoglycemic and hypolipidemic activity of moringa grown in hydroponics and soil in Ararat Valley. Functional foods in health and science and disease. 2023; 13(8): 398-408. DOI: https://doi.org/10.31989/ffhd.v13i8.1158

Trang, N. T. D., Schierup H., Brix H. Leaf vegetables for use in integrated hydroponics and aquaculture systems: Effects of root flooding on growth, mineral composition and nutrient uptake. African journal of biotechnology. 2010; 9(27): 4186-4196.

Vandam D.A., Anderson T. S., De villiers D., Timmons M. B. Growth and tissue elemental composition response of spinach (Spinacia oleracea) to hydroponic and aquaponic water quality conditions. Horti-culture. 2017. 3(32): 1-16. https://doi.org/10.3390/horticulturae3020032.

Von-Bieberstein P., Xu Y., Leslie Gunatilaka A. A., Gruener R. Biomass production and withaferin a synthesis by Withania somnifera grown in aeroponics and hydroponics. HortScience. 2014; 49(12): 1506-1509. DOI: 10.21273/HORTSCI.49.12.1506.

Web content https://hortamericas.com/blog/tech-doctor-steve/essential-plant-elements. Accessed on 22.6.2024.

Yadav S., Rao D., Sushma M. K., Kumar R., Yadav S. K. Book chapter on principles and methods of seed viability testing:Training manual on seed production, testing and storage in field and vegetable crops. Division of seed science and technology & ZTM and BPD Unit, ICAR, New Delhi -110012, India 1-9. 2023. Accessed on 21.2.2024.