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Differences Between the Feeding of Hydroponically Grown Curly Vegetables with Postbiotic Free Nutrient Solution and ATAGREEN Postbiotic Supplemented Nutrient Solution with Probiotics

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Abstract

This article presents a comparative analysis of the efficacy of two cultivation methods for curly lettuce crops: one involving the use of a probiotic-derived ATAGREEEN postbiotic-added nutrient solution, and the other relying on a nutrient solution without postbiotic. The analysis is supported by a comprehensive presentation of the experimental design, methodology, and results, as well as illustrative images. This study is discussed in detail under the following headings: basic principles of hydroponic agriculture, curly lettuce growing and its characteristics, the role of postbiotics in agriculture, the use of postbiotics in hydroponic agriculture, experimental design and methods, results and findings, analysis and interpretation of results, presentation of methods and results, discussion and recommendations. The experimental design is centred on the cultivation of curly lettuce plants in a hydroponic environment, with and without the addition of ATAGREEN postbiotic nutrient solutions. The methodology employed in the experiment, the cultivation conditions for the plants, the preparation of the nutrient solutions and the care of the plants were all determined in great detail. Furthermore, the experiment was designed to include a defined duration, measurement intervals, and data collection techniques. The results of the experiment demonstrated that the ATAGREEN postbiotic-supplemented nutrient solution exhibited notable advantages in curly lettuce growth. Plants treated with the ATAGREEN postbiotic solution exhibited accelerated growth, an increased number of leaves, and enhanced root systems. Additionally, plants treated with the ATAGREEN postbiotic solution demonstrated elevated resistance levels and greater resilience to detrimental organisms.

Key Words: Hydroponic farming, probiotic, postbiotic, curly lettuce, vegetables

1. Introduction

Hydroponic farming is a method of plant cultivation that involves the use of water solutions containing nutrients, as opposed to soil, which is the traditional approach. This system has been shown to conserve water and agricultural land (Al Ajmi et al., 2009; Richa et al., 2020; Rakesh and Javakrishna, 2022), whilst reducing the use of chemical fertilisers and pesticides, which are often necessary to combat plant diseases and harmful organisms (Richa et al., 2020). The ability to meet the nutrient requirements of plants in a controlled manner has been demonstrated to increase productivity and enable agricultural production in limited areas (Pandey et al., 2009; Despommier, 2013). The historical development of hydroponic agriculture is a process that extends from ancient times to modern practices. The evolution of hydroponic farming techniques can be traced back to the ancient irrigation canals of the Babylonian and Assyrian civilizations, and has been further refined over time to suit modern agricultural practices. Evidence suggests that in ancient Egyptian and Babylonian times, rock wool and clay were utilised to support the roots of plants in a floating position within water, thus facilitating the cultivation of aquatic flora (Kumar et al., 2023).

The foundations of modern hydroponic agriculture are believed to have been established in the 17th century through studies on the cultivation of plant roots in water (Sabry, 2021). Since the mid-20th century, hydroponic agriculture technology has undergone significant development, primarily driven by NASA's adoption of hydroponic systems for space exploration (Moraru et al., 2004). Subsequent advancements in hydroponic agriculture have been further developed and integrated with contemporary irrigation systems, resulting in the current practices observed today. Since the advent of the 20th century, hydroponic agriculture has emerged as a favoured agricultural modality, particularly in regions characterised by constrained water resources, an outcome that can be attributed to the escalating utilisation of fossil fuels (Pomoni et al., 2023).

1.1. Hydroponic Systems and Their Classification

Surface water technologies constitute a hydroponic system in which the roots of plants are placed on the water surface and are continuously supplied with fresh water and nutrient solution. This system provides plants with easy access to nutrient solutions, but good aeration is necessary to ensure oxygen uptake by the roots. The platforms that support the plant roots must also have an appropriate structure (López-Galvez et al., 2014). Film technologies constitute a hydroponic system in which the roots of plants come into contact with a nutrient solution contained in a thin film. This system necessitates sophisticated control mechanisms to ensure the stability of pH and electrical conductivity (EC) values in the water and nutrient solution. Notably, film technologies have been shown to conserve water by minimising evaporation levels in both water and nutrient solutions (Goddek et al., 2019).

Vertical hydroponic systems, such as cabinet and tower setups, are a notable example of this technological advancement. These systems are particularly well-suited to urban agriculture applications due to their ability to efficiently utilise limited spatial resources. The advantages of these systems include water savings, high productivity and pollution reduction. However, it is imperative to note that ensuring homogeneity in the root zone and the delivery of adequate nutrient solutions are of paramount importance (AlShrouf, 2017). Aquaponic farming is defined as a sustainable agricultural system that combines fish farming and hydroponic plant cultivation. The fundamental principle of this system is predicated on the filtration of the waste produced by the fish, with the process of conversion of the ammonium in the waste into nitrite and subsequently nitrate nutrients, and the development of plants by integrating this nutrient into the system. The nutrients so developed are absorbed by the plants cultivated in the hydroponic environment, thus purifying the water. The purified water is subsequently returned to the fish habitat. The continuous circulation of water in aquaponic farming systems enables the concurrent cultivation of both fish and plants (Goddek et al., 2019).

1.2. Nutrient Solutions and Properties employed in hydroponic Farming

Nutrient solutions utilised in hydroponic farming comprise essential nutrients that are indispensable for the development of plants throughout their life cycle (Trejo-Téllez & Gómez-Merino, 2012). These essential nutrients are defined as elements that are fundamental for the growth and development of plants. Nitrogen, phosphorus and potassium are recognised as essential nutrients, and it is imperative to ensure the appropriate ratios of these elements are present in the nutrient solution to facilitate optimal plant development. These elements are indispensable for various processes, including the formation of plant cells, photosynthesis, root development, seed formation, and general growth (De Rijck & Schrevens, 1999). Macronutrients, meanwhile, are elements required in large quantities for plant growth.

These elements include nitrogen, sulfur, calcium, magnesium, and phosphorus. Micronutrients, meanwhile, are elements that are required in minute quantities by plants. These micronutrients include iron, copper, zinc, manganese, molybdenum and chlorine. These nutrients are vital for the healthy development of plants, and their deficiency can have a detrimental effect on plant growth (Kumar et al., 2021). In hydroponic farming, nutrient solutions containing the essential nutrients required by plants are used. These solutions are formulated to be readily absorbable by the roots of the plants (Li et al., 2020; Ragaveena et al., 2021; Maharana & Koul, 2004).

1.3. The Advantages and Disadvantages of Hydroponic Agriculture

The advantages of hydroponic farming include water savings, labour savings, high productivity, control of nutrient uptake by plants, consistent crop quality, ease of protection from plant diseases and pests, and suitability for urban agriculture (Jones, 2016; Tripp, 2014). However, hydroponic farming also has disadvantages, including high set-up costs, complex maintenance, technical expertise, increased energy consumption, sensitive nutrient solution balance and difficulties in controlling root diseases (Tripp, 2014;Jones, 2016).

1.4. Environmental and Economic Impacts

In comparison with traditional agriculture, hydroponic agriculture is considered to be more environmentally friendly due to its ability to minimise water wastage, reduce erosion and pollution, and decrease chemical pollution (Jones, 2016). This is because the water and nutrients required by plants are supplied directly to the root system. Hydroponic agriculture is distinguished by its reduced reliance on chemical fertilisers and pesticides, making it a commendable method in terms of environmental sustainability. The advantage of soilless farming is that disease and pest organisms can be controlled more easily and chemical interventions can be reduced when necessary (Jones et al., 2020). From an economic perspective, hydroponic agriculture offers a competitive advantage in the market, resulting in high yields per unit area and the production of quality products (Mateus-Rodriguez et al., 2013; Gómez et al., 2019; Emani, 2018; Jafari et al., 2024).

1.5. Application Areas of Hydroponic Agriculture

Hydroponic farming is a favoured method in urban areas where agricultural land is limited. Vertical gardening is employed in urban areas where hydroponic systems are installed on the walls of buildings or on specially constructed platforms. This approach has the potential to establish sustainable agricultural models in urban areas (Michelon et al., 2019;Hamidon et al., 2020). Hydroponic agriculture is a method frequently employed by research and education centres. These centres favour hydroponic farming for the control of plant growth conditions, the study of different nutrient solutions and systems, and the teaching of agricultural practices. This approach facilitates the acquisition of significant insights into future agricultural methodologies (Hamidon et al., 2020).

1.6. New Technologies and Innovation

New technologies and innovations in hydroponic agriculture play an important role in the sustainability and efficiency of agriculture. Aquaponic systems represent a symbiotic integration of aquaculture and hydroponic agriculture. The waste of the fish is used as a nutrient solution for the plants, providing an ideal environment for the plants to grow. This system is highly advantageous in terms of water saving and sustainability. Another innovation is the use of artificial intelligence technologies in agriculture. The utilisation of artificial intelligence has been demonstrated to enhance the efficiency of hydroponic agriculture and to optimise plant-growing conditions. The integration of AI technologies into domains such as plant growth, disease control, and nutrient solution optimization has the potential to enhance agricultural productivity while fostering the development of a more sustainable agricultural model (Mamatha & Kavitha, 2023; Vanipriya et al., 2021).

1.7. Future Perspectives and Research Topics

The present status and future studies of hydroponic agriculture are a significant outcome of research into sustainable agricultural models. The findings, which include high productivity, water conservation, efficient space utilisation and precise control of plant growth conditions, are likely to ensure the preference for hydroponic agriculture in the future. It is anticipated that the research agenda will continue to evolve, with the emergence of novel innovations. The future direction of hydroponic agriculture will be focused on water conservation, sustainability, new technologies and the expansion of application areas. Potential future research topics include plant breeding, nutrient solution optimisation, energy saving and artificial intelligence integration.

2. Hydroponic Agriculture and Curly lettuce Cultivation

The present article analyses the difference between growing lettuce in hydroponic technique with probiotic supplemented nutrient solution and growing lettuce in nutrient solution without probiotic, with the results, methods and pictures to support this analysis. The study methodically explores the fundamental principles of hydroponic agriculture, curly lettuce cultivation, and its distinctive characteristics. It delves into the role of probiotics in agriculture, the utilisation of probiotics in hydroponic agriculture, experimental design and methodologies, results and findings, analysis and interpretation of results, presentation of results, results and discussion, conclusions and recommendations. Curly lettuce is one of the vegetables grown in hydroponic environments and known for its fibrous structure. Curly lettuce is also preferred by consumers for its fast growth, low water use and hygienic production possibilities. Curly lettuce grown in hydroponic environments can be grown in a more controlled environment than in soil farming, which can increase productivity (Dkhar & Bahadur, 2017;Kowalczyk et al., 2014).

2.1. The Role of Probiotics in Agriculture and Effects on Plant Development?

Studies have shown that formulations using probiotics and postbiotics, a type of probiotic product, are significantly more effective on living organisms (Aslan et al., 2023; Gökçe & Aslan, 2024; Tarhan-Celebi et al., 2024, Doğanay et al., 2025). Probiotics found in soil play an important role in promoting plant growth and improving soil health (Hossain et al., 201;John et al., 2020). Probiotics prevent harmful microorganisms from entering the roots of plants and increase nutrient absorption. In addition, they can strengthen plant immunity and provide resistance to diseases. Probiotics can also improve soil structure, increase water retention capacity and provide better nutrition for plants (de Souza Vandenberghe et al., 2017;Song et al., 2012). Some probiotics can promote root development of plants, allowing them to have stronger and deeper roots. Other types of probiotics can support the growth and development of plants by increasing their nutrient absorption. In addition, it is a known fact that probiotics have positive effects on plant growth, so they are increasingly used in agricultural practices (Woo & Pepe, 2018;Hossain et al., 2017).

2.2. Use of Probiotics in Hydroponic Farming

Using of probiotics in hydroponic farming plays an important role in the plant growing process (Kitwetch et al., 2023; Thomas et al., 2024). Probiotics support the development of root systems by containing beneficial bacteria and microorganisms that plants need. In this way, they help plants absorb nutrients more effectively. Probiotics can also increase the resistance of plants to diseases and help them cope with stress (Kim & Anderson, 2018; Hu et al, 2016). Therefore, the use of probiotics in hydroponic farming is of great importance for plant health and productivity.

2.3. Preparation of Probiotic Supplemented Nutrient Solutions

Nutrient solutions with probiotic additives contain beneficial microorganisms, as well as providing the nutrients that plants need. These solutions are typically derived from organic materials and are formulated in such a manner that they are readily absorbed by plants. The preparation of such solutions necessitates the utilisation of specialized equipment and ingredients, in addition to the meticulous measurement and application of the solution components. This ensures optimum utilization of plants (Zhong et al., 2017; Patel et al., 2010).

2.4. Effects of Probiotics on Curly lettuce Breeding

The effects of probiotics on curly lettuce cultivation can significantly improve plant growth and productivity. The use of probiotics has been shown to enhance the strength of plants' root systems, improve nutrient absorption, and augment their resilience to stress (Jones et al., 2019). Furthermore, probiotics have been shown to enhance plant resistance to diseases, thereby providing a protective effect against pathogens. Consequently, the utilisation of probiotics in curly lettuce cultivation has the potential to yield highly favourable outcomes in terms of plant health and productivity.

3. Material and Methods

The experimental design is centred on the cultivation of curly lettuce plants in hydroponics, with and without probiotic supplemented nutrient solutions. The methods employed in the experiment, the growing conditions of the plants, the preparation of nutrient solutions and the care of the plants were determined in detail. The duration of the experiment, the measurement intervals and the data collection techniques were also determined. The primary objective of the experiment was to make a comparison between the growth, development and yield characteristics of curly lettuce plants cultivated with probiotic supplemented nutrient solution and those of plants cultivated without probiotics. The underlying hypotheses posited that the probiotic-supplemented nutrient solution would exert a positive influence on plant growth, enhance plant health and yield, and augment stress tolerance in plants.

To this end, control groups were established and provided with equivalent growing conditions. In order to determine the effects of the probiotic supplemented solution, plants grown with this solution were used as control group. The control groups were maintained under conditions that were analogous with respect to plant growth, solution applications and maintenance.

4. Results and Discussion

The results of the comparison of curly lettuce plants grown with probiotic-supplemented and non-supplemented nutrient solutions revealed that probiotic-supplemented plants exhibited enhanced health and superior growth. The root development of the probiotic-fed plants exhibited enhanced strength, while the leaf coloration displayed heightened vibrancy. In contrast, plants cultivated with the unamended nutrient solution exhibited stunted growth, reduced vigor, and diminished productivity in comparison to those amended with probiotics. This observation lends further credence to the notion that probiotic supplementation exerts a beneficial influence on the development of curly lettuce plants.

Figure 1, Figure 2. the production process for the curly lettuce vegetables

Figures 1 and 2 illustrate the initiation of the production process for the curly lettuce seedlings in question, utilizing the same system and two distinct nutrient solutions.

Figure 3. The image of Curry roots

5. A comparison of Curly lettuce Plants Grown with Probiotic Supplemented and Non-Supplemented Nutrient Solutions, with Analysis and Interpretation of Results

Following analysis of the results of the difference between growing curly lettuce with probiotic-added nutrient solution and growing curly lettuce with probiotic-free nutrient solution by hydroponic technique, it was observed that probiotic-added plants grew faster and healthier. It was determined that the probiotic additive positively affected the root development of the plants and absorbed nutrients more efficiently. Furthermore, it was determined that probiotic supplementation increased the resistance of plants against diseases and positively influenced the overall plant health. This analysis thus demonstrates that probiotic supplementation exerts a substantial influence on the development of curly lettuce plants (Figure 3).

5.1. Analysis of the Data Obtained and Statistical Analyses

A thorough examination and statistical analysis of the data obtained during the experiment revealed clear differences in the development of curly lettuce plants grown with and without probiotic supplementation. Statistical analysis indicated that probiotic supplementation significantly augmented plant height, leaf growth, root length, and total yield. Furthermore, in comparison with the control groups, probiotic supplementation led to a marked enhancement in the general health status of the plants and optimized nutrient utilization.

5.2. A comparison of Curly lettuce Plants Grown with Probiotic Supplemented and Non-Supplemented Nutrient Solutions

Following analysis of the results of the difference between growing curly lettuce with probiotic-added nutrient solution and growing curly lettuce with probiotic-free nutrient solution by hydroponic technique, it was observed that probiotic-added plants grew faster and healthier. It was determined that the probiotic additive positively affected the root development of the plants and absorbed nutrients more efficiently. Furthermore, it was determined that probiotic supplementation increased the resistance of plants against diseases and positively influenced the overall plant health. This analysis thus demonstrates that probiotic supplementation exerts a substantial influence on the development of curly lettuce plants.

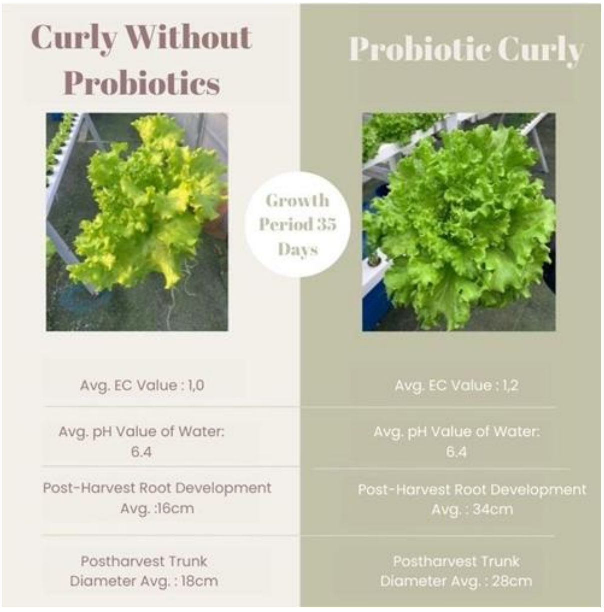

Figure 4. Measurement of some physical values in the growth stage of curly lettuce vegetable

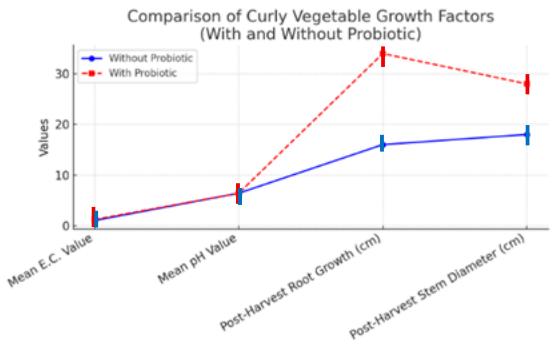

Figure 5. Graph of some physical changes of curly lettuce vegetable during growth stage

The experiment yielded results indicating that lettuce cultivated in a hydroponic technique using a nutrient solution fortified with probiotics exhibited superior growth characteristics in comparison with lettuce cultivated in the absence of probiotics. The experiment revealed that plants cultivated with the probiotic solution exhibited accelerated growth, an increased number of leaves, and healthier root systems. Furthermore, plants treated with the probiotic-amended solution exhibited enhanced resistance levels and greater resistance to harmful organisms.

The positive and beneficial effects of probiotic and postbiotic formulations on life forms have been documented (Aslan & Celebi, 2023; Aslan et al., 2025). The potential of probiotics in agricultural applications is significant. These microorganisms have been shown to enhance productivity by promoting plant growth, increasing plant resistance to harmful organisms, and enhancing plant resistance to diseases. Probiotics have been shown to play a significant role in improving plant growth and soil health (Hossain et al., 2017; John et al., 2020). They have been shown to enhance soil structure and increase water retention capacity, thereby ensuring optimal plant nutrition (de Souza Vandenberghe et al., 2017; Song et al., 2012). Furthermore, it has been documented that probiotics have a favorable impact on plant growth (Hossain and colleagues, 2017; Woo & Pepe, 2018).
The utilization of probiotic-enhanced nutrient solutions in the cultivation of curly lettuce plants has been demonstrated to yield several notable advantages. These include the provision of effective microorganisms that stimulate plant growth, facilitate nutrient absorption, and enhance plant resistance to harmful organisms. It has been observed that the general health status of plants improves and their productivity increases with the use of probiotic-added solutions. Further research is required to ascertain the full potential of probiotics in agricultural applications (Figure 4, Figure 5).

5. Conclusion

Following a comprehensive analysis of the outcomes, methodologies and images obtained from experiments conducted in a hydroponic environment, it was determined that the utilization of a nutrient solution augmented with probiotics exerted a favorable influence on the cultivation of curly lettuce plants. Observations revealed that the probiotic nutrient solution promoted faster growth, healthier plants and increased productivity. The findings of this study demonstrate that probiotic supplementation has significant advantages on curly lettuce cultivation. Future studies should focus on a detailed investigation of the effects of different probiotic strains, optimization of application dosages and evaluation of environmental effects. A detailed examination of the effects of different probiotic strains is recommended for future studies. In addition, optimizing probiotic application dosages and evaluating environmental effects are also important issues. In addition, investigating the long-term effects of probiotic-added nutrient solution and examining its effects on other plant species are among the suggested topics for future studies.

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Author Contribution
All authors shared equal tasks at all stages of the study.

Conflicts of Interest
Authors declare no conflicts of interests.

References

1. Al Ajmi, A., Salih, A. A., Kadim, I., & Othman, Y. (2009). Yield and water use efficiency of barley fodder produced under hydroponic system in GCC countries using tertiary treated sewage effluents. Journal of Phytology, 1(5), 342-348.
2. AlShrouf, A. (2017). Hydroponics, aeroponic and aquaponic as compared with conventional farming. American Scientific Research Journal for Engineering, Technology, and Sciences, 27(1), 247-255.
3. Aslan, İ., Çelebi, L. T., Çakıcı, B., & Bursalıoğlu, E. O. (2025). Oil-soluble novel skin microbiota friendly purifying oil cleanser formulation with postbiotics. Journal of Immunology and Clinical Microbiology, 9(4), 138-143.
4. Aslan, İ., Tarhan Celebi, L., Kayhan, H., Kizilay, E., Gulbahar, M. Y., Kurt, H., & Cakici, B. (2023). Probiotic formulations containing fixed and essential oils ameliorates SIBO-Induced gut

dysbiosis in rats. Pharmaceuticals, 16(7), 1041. https://doi.org/10.3390/ph16071041

5. Aslan, İ., & Çelebi, L. T. (2023). Postbiotics cosmetic formulation: In vitro efficacy studies on a microbiome friendly antiperspirant. Journal of Research in Pharmacy, 27, 2095-2105.
6. De Rijck, G., & Schrevens, E. (1999). Chemical feasibility region for nutrient solutions in hydroponic plant nutrition. Journal of Plant Nutrition, 22(2), 259-268.
7. Despommier, D. (2013). Farming up the city: The rise of urban vertical farms. Trends in Biotechnology, 31(7), 388-389. https://doi.org/10.1016/j.tibtech.2013.03.009
8. Doğanay, D., Aydin, M., Aslan, N., Çelik, İ., Doğanay A, Çelik Y. (2025). Parents' habits of using food supplements for their children: The impact of the COVID-19 pandemic process use of nutritional supplements in children during COVID-19. Journal of Research in Pharmacy, 29(1), 335-345. https://doi.org/10.12991/jrespharm.1644375
9. Dkhar, M. J., & Bahadur, V. (2017). Effect of different nutrient formulations on growth, yield and quality of lettuce (Lactuca sativa) cv. lollo rosso in a hydroponic system. The Allahabad Farmer, 73(1), 40-42.
10. Emani, D. S. K. R. (2018). A study on water use efficiency and pollution control by hydroponic technology. In International Conference on New Horizons in Green Chemistry & Technology (ICGCT).
11. 1Goddek, S., Joyce, A., & Kotzen, B. (2019). Aquaponics food production systems. Springer Open.
12. Gómez, C., Currey, C. J., Dickson, R. W., Kim, H. J., Hernández, R., Sabeh, N. C., ... Burnett, S. E. (2019). Controlled environment food production for urban agriculture. HortScience, 54(9), 1448-1458. https://doi.org/10.21273/HORTSCI14073-19
13. Gökçe, H. B., & Aslan, İ. (2024). Novel liposome–gel formulations containing a next generation postbiotic: Characterization, rheological, stability, release kinetic, and in vitro antimicrobial activity studies. Gels, 10(11), 746. https://doi.org/10.3390/gels10110746
14. Hamidon, M. H., Abd Aziz, S., Ahamed, T., & Mahadi, M. R. (2020). Design and development of smart vertical garden system for urban agriculture initiative in Malaysia. Jurnal Teknologi (Sciences & Engineering), 82(1). https://doi.org/10.11113/jt.v82.14324
15. Hossain, M. I., Sadekuzzaman, M., & Ha, S. D. (2017). Probiotics as potential alternative biocontrol agents in the agriculture and food industries: A review. Food Research International, 100, 63-73. https://doi.org/10.1016/j.foodres.2017.07.066
16. Hu, J., Wei, Z., Friman, V. P., Gu, S. H., Wang, X. F., Eisenhauer, N., ... Jousset, A. (2016). Probiotic diversity enhances rhizosphere microbiome function and plant disease suppression. mBio, 7(6), e01790-16. https://doi.org/10.1128/mBio.01790-16
17. Jafari, M., Asadi, E., & Fakheri Fard, A. (2024). Operational management of water quality to prevent physical, chemical, and microbial contaminations in hydroponic cultivation. Water Supply, 24(9), 3046-3060. https://doi.org/10.2166/ws.2024.081
18. John, C. J., Kumar, S., & Ge, M. (2020). Probiotic prospects of PGPR for green and sustainable agriculture. Archives of Phytopathology and Plant Protection, 53(19-20), 899-914. https://doi.org/10.1080/03235408.2020.1843412
19. Jones Jr, J. B. (2016). Hydroponics: A practical guide for the soilless grower (2nd ed.). CRC Press.
20. Kim, Y. C., & Anderson, A. J. (2018). Rhizosphere pseudomonads as probiotics improving plant health. Molecular Plant Pathology, 19(10), 2349-2359. https://doi.org/10.1111/mpp.12693
21. Kitwetch, B., Rangseekaew, P., Chromkaew, Y., Pathom-Aree, W., & Srinuanpan, S. (2023). Employing a plant probiotic actinomycete for growth promotion of lettuce (Lactuca sativa L. var. longifolia) cultivated in a hydroponic system under nutrient limitation. Plants, 12(22), 3793. https://doi.org/10.3390/plants12223793
22. Kowalczyk, K., Mirgos, M., Bączek, K., Niedzińska, M., & Gajewski, M. (2014). Effect of different growing media in hydroponic culture on the yield and biological quality of lettuce (Lactuca sativa var. capitata). Acta Horticulturae, 1142, 105-110. https://doi.org/10.17660/ActaHortic.2016.1142.17
23. Kumar, S., Singh, R. P., & Singh, N. K. (2023). Modern techniques for soilless cultivation. Springer.
24. Kumar, S., Kumar, S., & Mohapatra, T. (2021). Interaction between macro- and micro-nutrients in plants. Frontiers in Plant Science, 12, 665583. https://doi.org/10.3389/fpls.2021.665583

25. Li, C., Adhikari, R., Yao, Y., Miller, A. G., Kalbaugh, K., Li, D., & Nemali, K. (2020). Measuring plant growth characteristics using smartphone based image analysis technique in controlled environment agriculture. Computers and Electronics in Agriculture, 168, 105123. https://doi.org/10.1016/j.compag.2019.105123
26. Lopez-Galvez, F., Allende, A., Pedrero-Salcedo, F., Alarcon, J. J., & Gil, M. I. (2014). Safety assessment of greenhouse hydroponic tomatoes irrigated with reclaimed and surface water. International Journal of Food Microbiology, 191, 97-102. https://doi.org/10.1016/j.ijfoodmicro.2014.09.004
27. Maharana, L., & Koul, D. N. (2011). The emergence of Hydroponics. Yojana, 55, 39-40.
28. Mamatha, V., & Kavitha, J. C. (2023). Machine learning based crop growth management in greenhouse environment using hydroponics farming techniques. Measurement: Sensors, 25, 100665. https://doi.org/10.1016/j.measen.2022.100665
29. Mateus-Rodriguez, J. R., de Haan, S., Andrade-Piedra, J. L., Maldonado, L., Hareau, G., Barker, I., ... Benítez, J. (2013). Technical and economic analysis of aeroponics and other systems for potato mini-tuber production in Latin America. American Journal of Potato Research, 90, 357-368. https://doi.org/10.1007/s12230-013-9311-6
30. Michelon, N., Pistillo, A., Paucek, I., Pennisi, G., Bazzocchi, G., Gianquinto, G., ... Orsini, F. (2019). From microgarden technologies to vertical farms: Innovative growing solutions for multifunctional urban agriculture. Acta Horticulturae, 1298, 59-70. https://doi.org/10.17660/ActaHortic.2020.1298.9
31. Moraru, C., Logendra, L., Lee, T. C., & Janes, H. (2004). Characteristics of 10 processing tomato cultivars grown hydroponically for the NASA Advanced Life Support (ALS) Program. Journal of Food Composition and Analysis, 17(2), 141-154. https://doi.org/10.1016/j.jfca.2003.08.005
32. Pandey, R., Jain, V., & Singh, K. P. (2009). Hydroponics Agriculture: Its status, scope and limitations. Division of Plant Physiology, Indian Agricultural Research Institute.
33. Patel, A. K., Michaud, P., Singhania, R. R., Soccol, C. R., & Pandey, A. (2010). Polysaccharides from probiotics: New developments as food additives. Food Technology and Biotechnology, 48(4), 451-463.
34. Pomoni, D. I., Koukou, M. K., Vrachopoulos, M. G., & Vasiliadis, L. (2023). A review of hydroponics and conventional agriculture based on energy and water consumption, environmental impact, and land use. Energies, 16(4), 1690. https://doi.org/10.3390/en16041690
35. Ragaveena, S., Shirly Edward, A., & Surendran, U. (2021). Smart controlled environment agriculture methods: A holistic review. Reviews in Environmental Science and Bio/Technology, 20(4), 887-913. https://doi.org/10.1007/s11157-021-09591-z
36. Rakesh, J., & Jayakrishna, V. V. S. (2022). Vertical farming: Future of modern agriculture. Vigyan Varta, 3(6), 101-103.
37. Richa, A., Touil, S., Fizir, M., & Martinez, V. (2020). Recent advances and perspectives in the treatment of hydroponic wastewater: A review. Reviews in Environmental Science and Bio/Technology, 19(4), 945-966. https://doi.org/10.1007/s11157-020-09550-0
38. Sabry, F. (2021). Vertical farming: How shall we feed the three more billion people by 2050? (Vol. 4). One Billion Knowledgeable.
39. Song, D., Ibrahim, S., & Hayek, S. (2012). Probiotics in food and agricultural science. In E. C. Rigobelo (Ed.), Probiotics (pp. 1-20). IntechOpen.
40. Son, J. E., Kim, H. J., & Ahn, T. I. (2020). Hydroponic systems. In Plant factory (pp. 273–283). Academic Press.
41. Souza Vandenberghe, L. P., Garcia, L. M. B., Rodrigues, C., Camara, M. C., de Melo Pereira, G. V., de Oliveira, J., & Soccol, C. R. (2017). Potential applications of plant probiotic microorganisms in agriculture and forestry. AIMS Microbiology, 3(3), 629. https://doi.org/10.3934/microbiol.2017.3.629
42. Tarhan, L., Bursalıoğlu, E.O., Çakıcı, B., Genel, N., Kalbişen, H. T., & Aslan, İ. (2024). Can buttermilk (ayran) with its postbiotic content be used in the protection of colon health? Journal of Immunology and Clinical Microbiology, 9(4), 130-140.
43. Thomas, B. O., Lechner, S. L., Ross, H. C., Joris, B. R., Glick, B. R., & Stegelmeier, A. A. (2024). Friends and foes: Bacteria of the hydroponic plant microbiome. Plants, 13(21), 3069. https://doi.org/10.3390/plants13213069
44. Trejo-Téllez, L. I., & Gómez-Merino, F. C. (2012). Nutrient solutions for hydroponic systems. In T. Asao (Ed.), Hydroponics: A standard methodology

for plant biological researches (pp. 1-22). IntechOpen.
45. Tripp, T. (2014). Hydroponics advantages and disadvantages: Pros and cons of having a hydroponic garden. Speedy Publishing LLC.
46. Vanipriya, C. H., Malladi, S., & Gupta, G. (2021). Artificial intelligence enabled plant emotion expresser in the development hydroponics system. Materials Today: Proceedings, 45, 5034-5040. https://doi.org/10.1016/j.matpr.2020.10.640
47. Woo, S. L., & Pepe, O. (2018). Microbial consortia: Promising probiotics as plant biostimulants for sustainable agriculture. Frontiers in Plant Science, 9, 1801. https://doi.org/10.3389/fpls.2018.01801
48. Zhong, J., Zhang, F., Peng, Y., Ji, Z., Li, H., Li, S., ... Zhang, J. (2017). Mixed culture of probiotics on a solid-state medium: An efficient method to produce an affordable probiotic feed additive. Biotechnology and Bioprocess Engineering, 22, 758-766. https://doi.org/10.1007/s12257-017-0210-2