THE ORIGIN OF LETTUCE AND METHODS OF GROWING IT ON A GLOBAL SCALE (BASED ON HYDROPONICS).

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Abstract

Lettuce (Lactuca sativa L.) is a globally recognized leafy vegetable known for its nutritional value and versatility. The cultivation of lettuce in hydroponic systems, specifically using the Nutrient Film Technique (NFT) and Deep Flow Technique (DFT), has gained popularity for its efficiency and environmental sustainability. This study explores the effects of biofertilizers, including Plant Growth-Promoting Rhizobacteria (PGPR), Arbuscular Mycorrhizal Fungi (AMF), and microalgae, on the growth performance of lettuce in hydroponic systems. Lettuce plants were grown under controlled environmental conditions, with consistent nutrient solution management, including pH and electrical conductivity adjustments. Biofertilizers were applied at different concentrations (50% MF + B, 50% MF + AMF, 50% MF + microalgae) to assess their influence on growth parameters such as leaf area, leaf number, plant height, and biomass. The results revealed that biofertilizers significantly improved lettuce growth, with PGPR treatment yielding the greatest increase in leaf area and biomass. These biofertilizers contributed to enhanced nutrient availability and improved root health, promoting better growth compared to control groups. The findings highlight the potential of biofertilizers to optimize hydroponic lettuce production by improving resource use efficiency and fostering sustainable agricultural practices. This study offers valuable insights into hydroponic lettuce cultivation and the integration of biofertilizers as a promising solution for improving plant growth and yield in controlled environments.

Keywords. agricultural systems, environmental impact, resource management, hydroponic farming, soil-less systems, vegetable crops, nutrient uptake, biofertilizer application, crop yield, food production, farming technology, soil contamination, water use, organic farming, environmental sustainability, greenhouse agriculture.

Introduction

Asteraceae is a family of leafy vegetables that contains Lactuca sativa, often known as lettuce. This plant has gained international recognition for its use in the production of vegetable curries, salads, and soups. Furthermore, this herb has wonderful medicinal properties. Around the world, people cultivate lettuce, one of the most often consumed raw green leafy vegetables, for its deliciousness and high nutritional value. It's considered an important source of phytonutrients. Moreover, the plant contains essential constituents such as vitamins, minerals, and chemical substances. Its firm texture, subtle flavor, and nutritional advantages are highly valued. Lettuce, a cool-season crop, is commonly found in salads, sandwiches, and garnishes and can be farmed in several climates. Lettuce has gained popularity due to its versatility, nutritional benefits, and ability to enhance the aesthetic and taste of various dishes. Lettuce is a popular ingredient in many cuisines throughout the world, bringing a fresh and crisp flavor to meals all year round, whether as a garnish, the base of a salad, or the main item.

Materials and Methods

Lettuce (Lactuca sativa L.) was grown in hydroponic systems, including Nutrient Film Technique (NFT) and Deep Flow Technique (DFT), under controlled conditions. The growth media used were inert materials such as coconut fiber and rock wool. Lettuce seeds were planted in trays and transferred to hydroponic systems after germination. The nutrient solution used was a standard hydroponic mix with essential minerals, adjusted to maintain optimal pH (5.5-6.5) and electrical conductivity (EC) (1.5-2.0 mS/cm). The solution was replenished regularly to maintain nutrient availability. Temperature, humidity, and light were regulated in the growth chambers. The temperature was maintained between 20-24°C, with a relative humidity of 60-70%. Light intensity was set to 250-300 μmol/m²/s, with a 16-hour light cycle and 8-hour dark cycle. Biofertilizers, including PGPR, AMF, and microalgae, were added to the nutrient solution at varying concentrations (50% MF + B, 50% MF + AMF, 50% MF + microalgae). These biofertilizers were applied during the growing period to assess their effects on plant growth.

The origin of the lettuce leaf.

Lettuce (Lactuca sativa L.) is the world's most consumed and farmed leafy vegetable, with production increasing year after year. The entire area harvested globally in 2018 was anticipated to be more over 1.27 million hectares, with a total yield of around 27.3 million tons (FAOSTAT, 2018). Lettuce sativa is a member of the Asteraceae family, and its varieties are categorized into 12 categories based on its morphology (UPOV, 2019): Batavia, Butterhead, Cos, Frillice, Fris'ee d'Am'erique, Gem, Iceberg, Lollo, Multi-divided, Novita, Oakleaf, and Stem, as well as color (green, semi-red, and red). Wild relatives within the genus Lactuca exhibit remarkable variety, with more than 100 species (Lebeda et al., 2004). DeVries and van Raamsdonk (1994), DeVries (1997), and Mou (2008) provided the most recent thorough reviews of taxonomic and phenotypic assessments of lettuce cultivars. The crop is divided into seven major groupings of cultivars (including oilseed lettuce) that differ phenotypically; they are commonly referred to as morphotypes. The following treatment of L. sativa morphotypes comes from (Lebeda et al. 2007).

(a) **Butterhead lettuce** (var. capitata L. nidus tenerrima Helm) is a heading type with sensitive leaves that can possibly be eaten freshly prepared.

(b) **Crisphead lettuce** (var. capitata L. nidus jäggeri Helm) (Iceberg variety, Eissalat, Batavia) Eaten raw, this heading type has thick, crisp leaves with flabellate venation.

(c) **Cos lettuce** (var. longifolia Lam., var. romana Hort. in Bailey) (Romanian lettuce) Plants with tall loose heads, which are often tied up, and oblong stiff leaves with a noticeable midrib going almost to the apex can be eaten raw or cooked.

(d) **Cutting lettuce** (var. acephala Alef., syn. var. secalina Alef., syn. var. crispa L.) (gathering lettuce, loose-leaf, picking lettuce, Schnittsalat, Laitue à couper). Non-heading type is picked as full, open rosettes or, on occasion, as detached leaves, and eaten raw.

(e) **Stalk (Asparagus) lettuce** (var. angustana Irish ex Bremer, synonym var. asparagina Bailey, synonym L. angustana Hort. in Vilm.) Stem lettuce (Stengelsalat, Laitue-tige) refers to plants characterized by swelling stalks, used either fresh or cooked similarly to asparagus. Leaves may be consumed raw at an immature stage or prepared similarly to spinach (Lebeda, Křístková 1995).

(f) **Latin lettuce** (without scientific name) Plants possess loose heads characterized by thick, leathery leaves of a dark green hue, and are consumed uncooked.

(g) **Oilseed lettuce.** This kind is not eaten as a vegetable since its leaves have a bitter flavor. Oilseed lettuce has a high proportion (35%) of oil in the seeds, which are utilized for cooking.

Lettuce contains significant amounts of polyphenolic chemicals, vitamins A, C, and E, calcium, and iron (Romani, A. 2002). Partially due to its high raw consumption, it is an important source of dietary antioxidants and has high radical scavenging activity, which is frequently credited with aiding in the prevention of many chronic illnesses such as cancer and cardiovascular disease (Husain, S.R 1987, Cartea, M.E.2011). Lettuce is a cool-season vegetable that grows at temperatures between 7 and 24 ◦C. Lettuce (Lactuca sativa L.) is extensively produced and consumed across the world because of its health benefits: it is low in calories, fat, and salt, as well as an excellent source of fiber, iron, and vitamin C, among other bioactive substances (Kim et al., 2016). The rationale is that lettuce is regarded a modest supply of key antioxidant and health-related compounds, which can give vital information about the nutritional content of meals. These chemicals include phenols, anthocyanins, and carotenoids, among others (Simko, 2019). Its frequent use increases resistance to cancer, cardiovascular disease, and other chronic illnesses (Nicolle et al., 2004). It is eaten in salads, as a garnish in many dishes, or in sandwiches, highlighting the constant growth in consumption of fresh-cut salads (Damerum et al., 2020; Stuart, 2011) due to changes in consumption habits; thus, there is an increased demand for lettuce in a variety of colors, textures, and flavors.

Methods for growing lettuce leaves in hydroponics.

One of the most significant crop types cultivated in climate-controlled agriculture (CEA) is "short-cycle, single yield leafy green crops," such as lettuce, basil, and microgreens, a blend of various young leafy greens taken roughly 20 days after seeding (Kozai, 2018a). Lettuce is a fast-growing crop with a short growing cycle, high seeding density as well, and low energy consumption (Bantis et al. 2018; Zhang et al. 2018). A growing time frame of 21 days is typical in plant factory setups for optimum lettuce development (Ahmed et al., 2020). Because lettuce is a quick-growing plant, it has been raised and studied under a variety of situations. Hydroponic experiments provide just one illustration of this.

Hydroponics is a method of growing plants by immersing plant roots in a solution of nutrients, either without or with mechanical root supporting (Jones, J.B et al. 2005). It is also known as "controlled environment agriculture," or CEA, since growing plants hydroponically necessitates controlling numerous environmental parameters such as temperature of the water, light quantity and duration, humidity, solution pH, and mineral fertilizers (Pandey, R et al.2009). A hydroponic system, often known as hydroponic cultivation, is a technique of growing plants without the need of soil. The DFT and NFT systems are the most common hydroponic systems used to cultivate green crops. In the DFT system, solutions of nutrients are delivered to the plants any time the water level within the culture bed falls below the specified value, and they are recirculated and fed to the plants' bare roots at regular intervals in the cultivation bed that has a 1/100 slope. NFT systems and customized DFT systems like an ebb-and-flow mechanism have been widely deployed in plant industries. Hydroponic crop cultivation has been increasingly popular worldwide in recent years. Hydroponics is a sophisticated and growing crop production technology in which crops are produced in controlled conditions in liquid or solid media without soil by delivering basic and required nutrients. It is very productive, cautious of land and water, and respectful of the natural world. Hydroponics has shown to be a good alternative crop production method, with highly demanding systems that provide superior crop output (Savvas 2003; Rahman et al. 2018). This approach requires no arable land and allows for year-round production. This allows for year-round agricultural cultivation without the need of pesticides. A hydroponic system allows for a significant reduction in fertilizer input as well as a radical restriction, if not total removal, of nutrient leaking from greenhouses into the natural world (Avidan 2000; Rahman et al. 2017). Hydroponics provides a method of controlling soil-borne illnesses and insects, which is particularly useful in the tropics, wherever infestation are a big issue. Furthermore, hydroponics has benefits over soil-based systems in terms of fertilizer and water efficiency, temperature control, and insect prevention (Bradley, P. et al. 2001). One key feature of hydroponic culture is the requirement and capacity to manage the ambient temperature of the solution of nutrients or the root system with heaters or the cooling spiral. According to Rodrigues, L.R.F. et al. (2002), very slight variations in roots-zone temperature may have a considerable influence on root growth, depending on crop phenology and temperature duration. Water temperature can influence a variety of physiological processes during the development and growth of plants. According to studies, when the climate is above or below an optimum level, it can affect plant metabolic activities such as the accumulation of various metabolites such as phenolic substances, intake of nutrients, the chlorophyll pigment formation, photosynthesis, and, finally, plant growth and development (Nxawe, S.et al.2009).

Lettuce (Lactuca sativa L.) is a green plant that is frequently consumed fresh, hence sanitation in the production process is critical (Frasetya B.et al.2018). The use of hydroponic techniques for lettuce production provides advantages over conventional soil farming, including more sanitary lettuce plants, more uniform plant development, and the ability to plant at tight seeding distances (Hopkinson S.et al.2019). Aeroponics, the method of nutrient films (NFT), deep flux technique (DFT), ebb-flow system (EFS), and float raft scheme (FRS) are prominent hydroponic systems used for hydroponic lettuce growing (Qurrohman B.et al.2019). Each method offers the following advantages: Aeroponics can provide more dissolved oxygen than the other four systems; NFT systems can be put in vertically because the flow of water height in the setting up system is comparatively low + 3-5 mm, making it lighter than DFT; and the DFT system can provide nutrients and water even when the pump solution for nutrients is not working. The nutrient film method (NFT) is one of the most extensively used techniques in lettuce growing, with one advantage being increased salt tolerance (Promwee and Intana, 2022). Hydroponic systems vary greatly, making it difficult for new farmers and ordinary people to select the appropriate hydroponic system based on the commodity planted. Different hydroponic systems are primarily designed to deliver nutrients and water to plants (Wahome P K.et al.2011). An effective hydroponic system can deliver water and nutrients, but it must also be able to provide oxygen to the root zone.

One of the primary benefits of hydroponics is the accurate management of the nutrient solution, which at first can be modified several times during the growing cycle, optimizing nutrient supply based on the crop's vegetative cycle and enhancing yield and the quality of the goods (Velazquez-Gonzalez et al., 2022). Hydroponic leafy vegetable farming is becoming increasingly popular across the world due to effective resource management and high-quality agricultural products (Sharma et al., 2018).

Agriculture has a wide range of adverse environmental impacts, including significant demand on the availability of water, accounting for 69% of global groundwater (United Nations, 2021). It also causes rapid land depletion and soil contamination (Sharma et al., 2018). As a result, it is critical to seek out improved technologies that promote sustainable production by minimizing water use and waste creation, encouraging wastewater reuse, and conserving soil (Tomasi et al., 2014).

Soilless growing techniques are an alternative to traditional farming owing to proven benefits including shorter cultivating cycles, high cultivated plant densities, weed-free conditions, and the avoidance of crop rotation. Furthermore, these systems lower the likelihood of soil getting sick, pollution, and poverty (Tomasi et al., 2014). Hydroponics is a process that involves growing plants in fertilizer solutions. These systems are becoming increasingly popular among diverse solutions because to their efficient use of resources, food production, and environmental advantages (Buckseth et al., 2016; Sharma et al., 2018).

Fertilizers used in lettuce cultivation. There is a growing interest in innovative farming practices characterized by a high water use efficiency and a high yield per unit area, driven by novel plant nutrition techniques.Adopting new technologies has increased humanity's ability to address the challenges of limited resources. Hydroponics is considered an alternative to traditional agricultural systems (Majid et al., 2021; (Zappelini et al., 2024). The growing method known as hydroponics uses nutrient solutions to provide plants with the minerals they need to thrive. Plants have been mechanically supported by a variety of media made of organic materials, including peat moss, rock wool, sand, gravel, and coconut fibre (N. Sharma et al., 2018). By doing away with the requirement for soil and allowing for precise control over growing parameters such as preserving pH and electrical conductivity (EC) values within the ideal range for effective nutrient uptake by plants, hydroponic systems offer a novel method of growing plants in water solutions (Waiba et al., 2020). Due to a number of factors, such as inadequate drainage, soil sterility, soil deterioration, and the rise in soil-borne plant diseases, this farming technique has drawn a lot of interest recently as a potential remedy for the problems facing conventional agriculture. These soilless methods can be used to raise a variety of special and commercial crop species. For example, peppers, tomatoes, strawberries, and leafy greens like lettuce (Lee and Lee, 2015; Sharma et al., 2018; Waiba et al., 2020; Gumisiriza et al., 2022).Hydroponic systems are a method of growing plants without soil, extracting the necessary nutrients for their growth from a nutrient solution (Szekely & Jijakli, 2022) . These systems have emerged as a cornerstone technology in soilless vegetable production, offering a range of benefits from resource efficiency to optimized plant growth (Stegelmeier et al., 2022). By setting hydroponics in human-controlled greenhouses, natural disasters such as extreme temperature change, prolonged rainy periods, dry spells, and storms are avoided, allowing sustainable production during the entire year (Jenkins, A., Keeffe, G., & Hall, N. 2015). Hydroponic growth also reduces soil-borne problems, such as seed decay, seedling blight, and soil-inhabiting fungi-related diseases (Geilfus, 2019). One of the critical advantages of hydroponic systems is the ability to precisely control nutrient levels, electrical conductivity (EC), pH, and oxygenation (Nguyen et al., 2016),thereby optimizing plant growth and resources. Hydroponic systems are more water-efficient than traditional soil-based cultivation, making them an attractive option for sustainable agriculture. These systems can be categorized into several types, including Nutrient Film Technique (NFT), Deep Water Culture (DWC), and Aeroponics, each with unique advantages and applications. NFT, for instance, employs a thin film of nutrient solution that flows over the roots, powered by a water pump, providing a constant supply of nutrients and oxygen (N. Sharma et al., 2018). This system is particularly effective for leafy greens and herbs, which require less support and can thrive in these conditions.On the other hand, DWC submerges the plant roots in a nutrient solution, using air stones to oxygenate the water (Nursyahid et al., 2021). This system is well-suited for plants that require more support and a stable environment, such as tomatoes and cucumbers. Aeroponics represents the most technologically advanced form of hydroponics, where nutrient solution is misted directly onto the roots, maximizing oxygen exposure (Stegelmeier et al., 2022). Hydroponics is a contemporary agricultural system providing precise control over growing conditions, potentially enhancing productivity. Biofertilizers are environmentally friendly, nextgeneration fertilizers that augment product yield and quality in hydroponic cultivation (Dasgan et al., n.d.). These soilless systems' efficient and cost-effective water management can reduce the amount of water used in crop cultivation. As a result, a lot of study has been conducted to boost productivity both qualitatively and quantitatively. Microalgae and plant syanobacter can be utilised to develop sustainable and ecologically friendly farming systems. These various compounds promote plant development when applied in small amounts to the soil or directly to the leaf surface. In addition to reducing fertiliser consumption and nutrient solution concentrations in hydroponic farming systems, syanobacteria and microalgae have been demonstrated to enhance crop performance in these systems (Vernieri et al., 2006; (Povero et al., 2016).

One of the most well-known green vegetables in the world, lettuce has several purposes beyond just nourishment. Customers can select from a variety of varieties in the lettuce group. Furthermore, lettuce is a great source of bioactive substances with associated health advantages, including polyphenols, carotenoids, and chlorophyll. At the same time, different types of lettuce have distinct nutrient compositions and antioxidant components, particularly red and green lettuce. The makeup of lettuce, especially its antioxidants, which can act as nutrients, determines how beneficial eating it is (Shi et al., 2022). Lettuce (Lactuca sativa L.) belongs to the Asteraceae family and originates in the Mediterranean. It is a successful and diverse plant distributed worldwide. The first cultivated lettuce appears in several primitive writings in early 2680 BCE as a medicinal herb. The Asteraceae can be considered the family of plants with a large number of species, around 23,000 to 30,000 (Funk et al., 2005). Formally, there are seven different types in the lettuce group, including Cos (a.k.a. Romaine), Butterhead, Leaf (a.k.a. Cutting), Stalk (or Asparagus), Crisphead (a.k.a. Iceberg), Latin, and Oilseed. The whole heads of lettuce and the freshcut form are the common products in the market. The colors, shapes, and nutrients are important factors to affect consumer purchase choice (Mampholo et al., 2016). Lettuce is low in calories and high in water (94–95%) (Yang et al., 2022). Additionally, it is a great source of vitamins, minerals, and bioactive substances with associated health advantages like polyphenols, carotenoids, and chlorophyll. Furthermore, the quantities and compositions of phytochemicals vary among types. According to certain studies, red lettuce has relatively higher phenolic contents than green lettuce for both types. Red lettuce is therefore an excellent daily dietary source of antioxidants (Wilson et al., 2004). It was discovered that lettuce has a high vitamin C content(Medina-Lozano et al., 2021). Usually, lettuce leaves are eaten raw in salads or in minimally processed foods like mixed salads, fresh-cut products, and infant food. Customers in the market are in desire of it all year round (Martínez-Sánchez et al., 2012). Lettuce has a short vegetation period. The microgreens can be harvested at around 15 days, the heads can be harvested at 45-50 days, and after around 120 days, the seeds can be harvested. Lettuce can be stored in cold rooms, at temperatures of 0-1 °C and 95% humidity, for up to 10-12 days (Güzel et al., 2021).Lettuce can be found in a range of colours, sizes and forms, selected upon cultivation according to the tenets desired. Lettuce is relatively easy to cultivate and has a short growing cycle, making it suitable for year-round hydroponic cultivation. Biofertilizers had a statistically significant effect on the number and area of lettuce plants' leaves. In comparison to the 50% MF treatment, the leaf area rose by 32.33%, 19.71%, and 13.73% for PGPR, AMF, and microalgae, respectively. In comparison to the 50% MF treatment, the number of leaves per plant in the 50% MF + B, 50% MF + AMF, and 50% MF + microalgae treatments was found to be 8.16%, 5.24%, and 4.66% greater, respectively. The primary photosynthetic component of plants is the leaf. The microorganism's generation of plant growth regulators and the biofertilizers' improved nutrient availability may have contributed to the increase in leaf area shown in this instance. As a result of this event, plant growth and yield were encouraged. An effective photosynthetic organ, the biofertilizers' increased leaf area probably helped the plants produce more carbohydrates (Boubaker et al., 2023; Dasgan et al., 2023).

Conclusion and Recommendations

This study demonstrates the significant positive effects of biofertilizers, including Plant Growth-Promoting Rhizobacteria (PGPR), Arbuscular Mycorrhizal Fungi (AMF), and microalgae, on the growth and development of lettuce (Lactuca sativa L.) in hydroponic systems. The application of these biofertilizers resulted in enhanced growth parameters such as increased leaf area, higher leaf number, and improved biomass production. Specifically, PGPR showed the most pronounced effect, promoting superior root health and better nutrient uptake, which led to healthier, more vigorous plants. Hydroponic systems like Nutrient Film Technique (NFT) and Deep Flow Technique (DFT) effectively supported lettuce growth by providing a controlled and consistent nutrient environment.

The findings suggest that incorporating biofertilizers in hydroponic systems offers a promising, sustainable alternative to traditional farming methods. It reduces reliance on synthetic fertilizers, optimizes resource use, and potentially enhances both the yield and quality of crops.

To further optimize this approach, additional research is needed to explore the long-term effects of various biofertilizer combinations and their impact on nutrient content, disease resistance, and other growth parameters across different lettuce cultivars. It would also be beneficial to conduct sustainability assessments that compare hydroponic systems with traditional soil-based agriculture in terms of water, energy consumption, and environmental impact. For large-scale commercial production, integrating biofertilizers into hydroponic systems could reduce environmental footprints while improving productivity. Furthermore, economic feasibility studies should be carried out to assess the cost-effectiveness of biofertilizer application in hydroponics to encourage its adoption by growers. By combining these approaches, hydroponic systems can become a key player in sustainable, resource-efficient agriculture.

Referance

1) FAOSTAT. Statistics of the Food and Agriculture Organization of the United Nations. (2018). http://www.fao.org/faostat/en/#data/QC/ Accesed 21 June 2020.

2) UPOV (International Union for the Protection of New Varieties of Plants) (2019) Guidelines for the Conduct of Tests for Distinctness, Homogeneity, and Stability. Document UPOV TG/13/11 Rev, Geneva, Switzerland.

3) Lebeda, A., Doleˇzalov´a, I., & Astley, D. (2004). Representation of wild Lactuca spp. (Asteraceae, Lactuceae) in world genebank collections. Genetic Resources and Crop Evolution, 51(2), 167–174. https://doi.org/10.1023/B:GRES.0000020860.66075.f7.

4) Rodenburg C.M., 1960. Varieties of Lettuce. An International Monograph. Zwolle, W.E.J. Tjeenk Willink.

5) Mou b., 2008. Lettuce. In: PROHENS J., NUEZ F. (eds), Handbook of Plant Breeding. Vegetables I. Asteraceae, Brassicaceae, Chenopodiaceae, and Cucurbitaceae. New York, Springer Science: 75–116.

6) Lebeda A., Křístková E., 1995. Genetic resources of vegetable crops from the genus Lactuca. Horticultural Science (Prague), 22: 117–121.

7) Romani, A.; Pinelli, P.; Galardi, C.; Sani, G.; Cimato, A.; Heimler, D. Polyphenols in Greenhouse and Open-Air-Grown Lettuce. Food Chem. 2002, 79, 337–342. [CrossRef]

8) Husain, S.R.; Cilurd, J.; Cillard, P. Hydroxyl radical scavenging activity of Flavonoids. Phytochemistry 1987, 26, 2489–2491. [CrossRef]

9) Cartea, M.E.; Francisco, M.; Soengas, P.; Velasco, P. Phenolic Compounds in Brassica Vegetables. Molecules 2011, 16, 251–280. [CrossRef] [PubMed]

10) Kozai, T., 2018a. Current status of plant factories with artificial lighting (PFALs) and smart PFALs. In: Kozai, T. (Ed.), Smart Plant Factory: The Next Generation Indoor Vertical Farms. Springer, Singapore, pp. 3–13. https://doi.org/10.1007/978-981-13- 1065-2_1

11) Bantis, F., Smirnakou, S., Ouzounis, T., Koukounaras, A., Ntagkas, N., Radoglou, K., 2018. Current status and recent achievements in the field of horticulture with the use of light-emitting diodes (LEDs). Sci. Hortic. 235, 437–451. https://doi.org/10.1016/ j.scienta.2018.02.058.

12) Zhang, X., He, D., Niu, G., Yan, Z., Song, J., 2018. Effects of environment lighting on the growth, photosynthesis, and quality of hydroponic lettuce in a plant factory. Int. J. Agricult. Biol. Eng. 11, 33–40. https://doi.org/10.25165/j.ijabe.20181102.3240.

13) Ahmed, H.A., Yu-Xin, T., Qi-Chang, Y., 2020a. Optimal control of environmental conditions affecting lettuce plant growth in a controlled environment with artificial lighting: a review. S. Afr. J. Bot. 130, 75–89. https://doi.org/10.1016/j. sajb.2019.12.018.

14) Jones, J.B., Jr. Hydroponics: A Practical Guide for the Soilless Grower, 2nd ed.; CRC Press: Boca Raton, FL, USA, 2005; p. 423.

15) Pandey, R.; Jain, V.; Singh, K.P. Hydroponics agriculture: Its status, scope and limitations. Division of Plant Physiology, Indian Agric. Res. Inst. 2009, 20–29.

16) Savvas D. (2003) Hydroponics: A modern technology supporting the application of integrated crop management in greenhouse. Journal of Food, Agriculture and Environment, 1: 80-86.

17) Rahman M.J. Quamruzzaman M. Uddain J. Sarkar M.D. Islam M.Z. Zakia M.Z. Subramaniam S. (2018) Photosynthetic response and antioxidant content in bitter gourd as influenced by organic substrates and nutrient solution. HortScience, 53(9): 1314-1318.

18) Avidan A. (2000) The use of substrates in Israel. World congress on soilless culture on agriculture in the coming millennium. Maale Hachamisha, Israel. pp.17.

19) Rahman M.J. Khatun P. Quamruzzaman M. Chawdhery M. R. A. Zakia M. Z. Raihan A. Sarkar M. D. Ali M. M. Ahmed S. (2017a) Growth and yield of different lettuce

varieties grown in the hydroponic system in Bangladesh. Bangladesh Journal of Horticulture, 3(2), Series 2: 23-29.

20) Bradley, P.; Marulanda, C. Simplified hydroponics to reduce global hunger. Acta Hort. 2001, 554, 289–295. [CrossRef]

21) Rodrigues, L.R.F. Growing by hydroponics: Hydroponic cultivation techniques and environmental control in the management of pests, diseases and plant nutrition in a protected environment. Jaboticabal FUNEP 2002, 726.

22) Nxawe, S.; Laubscher, C.; Ndakidemi, P. Effect of regulated irrigation water temperature on hydroponics production of Spinach (Spinacia oleracea L.). Afr. J. Agric. Res. 2009, 12, 1442–1446.

23) Frasetya B, Taofik A and Firdaus R K 2018 Evaluation fo Variation Electrical Conductivity Value on The Growth of Lettuce (Lactuca sativa L.) In The NFT System J. Agro 5 2 95–102

24) Hopkinson S and Harris M 2019 Effect of pH on Hydroponically Grown Bush Beans (phaseolus vulgaris) Int. J. Environ. Agric. Biotechnol. 4 1 142–145

25) Qurrohman B F T 2019 Hydroponic Lettuce Plant Concept and Application (Bandung: Research and Publication Center of UIN SGD Bandung)

26) Promwee, A.; Intana, W. Trichoderma asperellum (NST-009): A potential native antagonistic fungus to control Cercospora leaf spot and promote the growth of 'Green Oak' lettuce (Lactuca sativa L.) cultivated in the commercial NFT hydroponic system. Plant Protection Science, v.58, p.139-149, 2022. https://doi.org/10.17221/69/2021-PPS

27) Wahome P K, Oseni T O, Masarirambi M T and Shongwe V D 2011 Effects of Different Hydroponics Systems and Growing Media on the Vegetative Growth, Yield and Cut Flower Quality of Gypsophila (Gypsophila paniculata L.) World J. Agric. Sci. 7 6 692–698

28) Velazquez-Gonzalez, R.S., Garcia-Garcia, A.L., Ventura-Zapata, E., Barceinas-Sanchez, J. D.O., Sosa-Savedra, J.C., 2022. A review on hydroponics and the technologies associated for medium-and small-scale operations. Agriculture 12, 646.

29) Sharma, N., Acharya, S., Kumar, K., Singh, N., Chaurasia, O.P., 2018. Hydroponics as an advanced technique for vegetable production: an overview. J. Soil Water Conserv. 17 (4), 364–371.

30) United Nations, 2021. The United Nations World Water Development Report 2021:Valuing Water.

31) Tomasi, N., Dalla Costa, L., Pinton, R., Cortella, G., Terzano, R., Mimmo, T.,Scampicchio, M., Cesco, S., 2014. New "solutions" for floating cultivation system of ready-to-eat salad: A review. Trends Food Sci. Technol. 46, 267–276. https://doi.

32) Buckseth, T., Sharma, A.K., Pandey, K.K., Singh, B.P., Muthuraj, R., 2016. Methods of pre-basic seed potato production with special reference to aeroponics—A review. Sci. Hortic. (Amst.). 204, 79–87. https://doi.org/10.1016/j.scienta.2016.03.041.

33) Kim, M.J., Moon, Y., Tou, J.C., Mou, B., Waterland, N.L., 2016. Nutritional value, bioactive compounds and health benefits of lettuce (Lactuca sativa L.). J. Food Compos. Anal. 49, 19–34. https://doi.org/10.1016/j.jfca.2016.03.004.

34) Simko, I., 2019. Genetic variation and relationship among content of vitamins, pigments, and sugars in baby leaf lettuce. Food Sci. Nutr. 7, 3317–3326.

35) Nicolle, C., Cardinault, N., Gueux, E., Jaffrelo, L., Rock, E., Mazur, A., Amouroux, P., R´em´esy, C., 2004. Health effect of vegetable-based diet: lettuce consumption improves cholesterol metabolism and antioxidant status in the rat. Clin. Nutr. 23, 605–614.

36) Damerum, A., Chapman, M.A., Taylor, G., 2020. Innovative breeding technologies in lettuce for improved post-harvest quality. Postharvest Biol. Tec. 168, 111266.

37) Stuart, D., 2011. Nature" is Not Guilty: foodborne Illness and the Industrial Bagged Salad. Sociol. Ruralis. 51, 158–174.

38) Majid, M., Khan, J. N., Shah, Q. M., Masoodi, K. Z., Afroza, B., & Parvaze, S. (2021). Evaluation of hydroponic systems for the cultivation of Lettuce (Lactuca sativa L., var. longifolia) and comparison with protected soil based cultivation. *Agric. Water Manag*.

39) Zappelini, J., Pescador, R., Girardello, G. M., Souza, P. P., Borghezan, M., & Oliveira, J. L. (2024). Physiological alterations in 'Rubinela'lettuce (Lactuca sativa L.) cultivated in conventional and hydroponic systems. *Acta Sci. Agron*, *46*.

40) Sharma N, Acharya S, Kumar K Singh N, Chaurasia OP. (2018b). *Hydroponics as an advanced technique for vegetable production: An overview*. Journal of Soil and Water Conservation 17 (4): 364-371. https://doi.org/10.5958/2455- 7145.2018.00056.5.

41) Waiba, K. M., Sharma, P., Sharma, A., Chadha, S., & Kaur, M. (2020). Soilless vegetable cultivation: a review. *Journal of Pharmacognosy and Phytochemistry*, *9*(1), 631–636.

42) Lee, S., & Lee, J. (2015). Beneficial bacteria and fungi in hydroponic systems: Types and characteristics of hydroponic food production methods. *Scientia Horticulturae*, *195*, 206–215. https://doi.org/10.1016/j.scienta.2015.09.011

43) Gumisiriza, M. S., Kabirizi, J. M. L., Mugerwa, M., Ndakidemi, P. A., & Mbega, E. R. (2022). Can soilless farming feed urban East Africa? An assessment of the benefits and challenges of hydroponics in Uganda and Tanzania. *Environmental Challenges*, *6*(100413), 100413. https://doi.org/10.1016/j.envc.2021.100413

44) Szekely, I., & Jijakli, M. H. (2022). Bioponics as a promising approach to sustainable agriculture: A review of the main methods for producing organic nutrient solution for hydroponics. *Water*, *14*(23), 3975. https://doi.org/10.3390/w14233975

45) Stegelmeier, A. A., Rose, D. M., Joris, B. R., & Glick, B. R. (2022). The use of PGPB to promote plant hydroponic growth. *Plants*, *11*(20), 2783. https://doi.org/10.3390/plants11202783

46) Jenkins, A., Keeffe, G., & Hall, N. (2015). Planning urban food production into today's cities. Future of Food: Journal on Food, Agriculture and Society, 3(1), 35–47. http://f utureoffoodjournal.org/index.php/journal/article/view/149. (n.d.).

47) Geilfus, C.-M. (2019). Hydroponic Systems in Horticulture. In *Controlled Environment Horticulture* (pp. 35–40). Springer International Publishing.

48) Nguyen, N. T., McInturf, S. A., & Mendoza-Cózatl, D. G. (2016). Hydroponics: A versatile system to study nutrient allocation and plant responses to nutrient availability and exposure to toxic elements. *Journal of Visualized Experiments: JoVE*, *113*. https://doi.org/10.3791/54317-v

49) Nursyahid, A., Setyawan, T. A., Sa'diyah, K., Wardihani, E. D., Helmy, H., & Hasan, A. (2021). Analysis of Deep Water Culture (DWC) hydroponic nutrient solution level control systems. *IOP Conference Series. Materials Science and Engineering*, *1108*(1), 012032. https://doi.org/10.1088/1757-899x/1108/1/012032.

50) Dasgan, H. Y., Yilmaz, M., Dere, S., Ikiz, B., & Gruda, N. S. (2023). *Bio-fertilizers reduced the need for the mineral fertilizers in soilless grown ˙ capia pepper. Horticulturae 2023, 9, 188*. Horticulturae 2023, 9, 188.

51) Vernieri, P., Borghesi, E., Tognoni, F., Serra, G., Ferrante, A., & Piagessi, A. (2006). Use of biostimulants for reducing nutrient solution concentration in floating system. *Acta Horticulturae*, *718*, 477–484. https://doi.org/10.17660/actahortic.2006.718.55

52) Povero, G., Mejia, J. F., Di Tommaso, D., Piaggesi, A., & Warrior, P. (2016). A systematic approach to discover and characterize natural plant biostimulants. *Frontiers in Plant Science*, *7*, 435. https://doi.org/10.3389/fpls.2016.00435

53) Shi, M., Gu, J., Wu, H., Rauf, A., Emran, T. B., Khan, Z., Mitra, S., Aljohani, A. S. M., Alhumaydhi, F. A., & Al-Awthan, Y. S. (2022). *Phytochemicals, Nutrition, Metabolism, Bioavailability, and Health Benefits in Lettuce—A Comprehensive Review*. Antioxidants 2022, 11, 1158. https://doi.org/ 10.3390/antiox11061158.

54) Funk, V. A., Bayer, R. J., Keeley, S., Chan, R., Watson, L., Gemeinholzer, B., Schilling, E., Panero, J. L., Baldwin, B. G., & Garcia-Jacas, N. (2005). Everywhere but Antarctica: Using a supertree to understand the diversity and distribution of the Compositae. *Biol. Skr*, *55*, 343–374.

55) Mampholo, B. M., Maboko, M. M., Soundy, P., & Sivakumar, D. (2016). Phytochemicals and overall quality of leafy lettuce (Lactuca sativa L.) varieties grown in closed hydroponic system. *J. Food Qual*, *39*, 805–815.

56) Yang, X., Gil, M. I., Yang, Q., & Tomás-Barberán, F. A. (2022). Bioactive compounds in lettuce: Highlighting the benefits to human health and impacts of

preharvest and postharvest practices. *Comprehensive Reviews in Food Science and Food Safety*, *21*(1), 4–45. https://doi.org/10.1111/1541-4337.12877

57) Wilson, P., Morrison, S., Hedges, L., Kerkhofs, N., & Lister, C. (2004). Phenolics contribute significantly to higher antioxidant activity of red lettuce compared to green lettuce. In *Proceedings of the XXII International Conference on Polyphenols* (pp. 273–274).

58) Medina-Lozano, I., Bertolín, J. R., & Díaz, A. (2021). Nutritional value of commercial and traditional lettuce (Lactuca sativa L.) and wild relatives: Vitamin C and anthocyanin content. *Food Chemistry*, *359*(129864), 129864. https://doi.org/10.1016/j.foodchem.2021.129864

59) Martínez-Sánchez, A., Luna, M. C., Selma, M. V., Tudela, J. A., Abad, J., & Gil, M. I. (2012). *Baby-leaf and multi-leaf of green and red lettuces are suitable raw materials for the fresh-cut industry.* . Postharvest Biol. Technol. 2012, 63, 1–10.

60) Güzel, M. E., Coşkunçelebi, K., Kilian, N., Makbul, S., & Gültepe, M. (2021). Phylogeny and systematics of the Lactucinae (Asteraceae) focusing on their SW Asian centre of diversity. *Plant Systematics and Evolution*, *307*(1). https://doi.org/10.1007/s00606-020-01719-y

61) Boubaker, H., Saadaoui, W., Dasgan, H. Y., Tarchoun, N., & Gruda, N. S. (2023). Enhancing seed potato production from in vitro plantlets and microtubers through biofertilizer application: Investigating effects on plant growth, tuber yield, size, and quality. *Agronomy*, *13*.