

EVALUATION OF CIRCULATORY AND NON-CIRCULATORY HYDROPONIC TECHNIQUES ON YIELD AND QUALITY OF SPINACH AND LETTUCE AT COLD DESERT TRANS HIMALAYAN REGION OF INDIA

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in

Soil Science and Agriculture Chemistry

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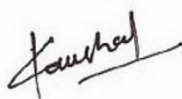


LOVELY PROFESSIONAL UNIVERSITY, PUNJAB

2023

DECLARATION

I, hereby declared that the presented work in the thesis entitled “**Evaluation of Circulatory and Non-circulatory Hydroponic Techniques on Yield and Quality of Spinach and Lettuce at Cold Desert Trans Himalayan Region of India**” in fulfilment of degree of **Doctor of Philosophy (Ph. D.)** is outcome of research work carried out by me under the supervision Name of supervisor: Dr. Kamini Kumar, Associate Professor, Department of Soil Science, School of Agriculture, Lovely Professional University, Jalandhar, Punjab, India. And Name of Co-Supervisor: Dr. Somen Acharya, Scientist-E, Defence Institute of High Altitude Research, Defence Research and Development Organisation (DIHAR-DRDO), Leh, Union Territory-Ladakh, India. In keeping with general practice of reporting scientific observations, due acknowledgements have been made whenever work described here has been based on findings of other investigator. This work has not been submitted in part or full to any other University or Institute for the award of any degree.



23-06-2023

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CERTIFICATE

This is to certify that the work reported in the Ph. D. thesis entitled “**Evaluation of Circulatory and Non-circulatory Hydroponic Techniques on Yield and Quality of Spinach and Lettuce at Cold Desert Trans Himalayan Region of India**” submitted in fulfillment of the requirement for the reward of degree of **Doctor of Philosophy (Ph.D.)** in the Department of Soil Science, School of Agriculture is a research work carried out by **Kaushal Kumar**, Registration No.11900926, is bonafide record of his/her original work carried out under my supervision and that no part of thesis has been submitted for any other degree, diploma or equivalent course.



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Abstract

*Hydroponic cultivation is a relatively new soilless technique that produces fresh vegetable in places where environmental stress (cold, heat, desert, etc.) is a major problem or constrains of space or on arable land. The Trans Himalayas high-altitude cold desert regions between 32° 15 and 36° latitude and 75° 15 to 80° 15 longitude in the northern part of India. In India union territory Ladakh and Himachal Pradesh district Lahaul and Spiti. Double-cropping is only feasible in a small area that falls below an altitude of around 3500 m, hence single-cropping predominates. Irrigation is the only method used for agricultural production. Since rivers in the area are underutilized for agricultural purposes and glaciers are the primary supply of water for irrigation, this area could be used for hydroponic farming. Lettuce (*Lactuca sativa*) is an important source of vitamin K, A, with higher concentrations of the pro-vitamin A and β -carotene, as well as excellent source of folate and iron (Source: FAO). Lettuce mostly consumed as with burger and extremely demanding in hotels and restaurants as fresh salad. Lettuce is mostly used leafy green that is easily cultivable in a commercial hydroponic system and mostly grown using the nutrient film technique (NFT) Hydroponic vertical farming helps to increase per unit area production (Touliatos et al., 2016). Spinach (*Spinacia oleracea*) is an edible leafy vegetable and commonly used as a vegetable, leafy leaves can be eaten fresh, frozen, canned, diced, or dehydrated. When spinach is utilized fresh, frozen, steamed, or briefly boiled, it has a high nutritional value. It is a good source of iron, folate, magnesium, manganese, vitamin A, C, and K. The nutrients riboflavin and pyridoxine, vitamin E, calcium, potassium, and dietary fiber are all abundant in spinach. (Source: FAO). Growing of leafy vegetables through hydroponic technique has advance cultivation practise compared to soil, like early maturity (marketable yield) and uniform development of plants. Consequently, the location presents significant obstacles to the year-round production of fresh vegetables. Hydroponic technology can be an alternative to grow vegetables in the region round the year and this technology never been used in this cold desert region for growing crops.*

The experiment was conducted in hydroponic structures specially designed for leafy vegetables (lettuce and spinach) cultivation viz. vertical and horizontal circulated (NFT), non-circulated systems and compares them with soil cultivation in open naturally ventilated double layer polycarbonate green house at Ladakh India. Lettuce and spinach grown in vertical circulated system showed significant differences ($P < 0.05$) in plant growth characters namely, the of plant height, number of leaves, leaf area, fresh weight, and yield comparison to horizontal NFT, non-circulated and soil system. Nitrate content, soluble sugar content and total sweetness index of

fresh lettuce and spinach was found significantly higher in vertical and horizontal NFT system compared to non-circulated and soil grown system which indicated better crispiness of the fresh produce. Mineral nutrient contents (Ca, Mg, B, Cu, Mn, Zn, Fe and Ni) were also found higher in circulated NFT system compared to other systems studied. From the overall study it can be concluded that lettuce and spinach grown in NFT system produce significantly higher yield with better nutritional quality as compared to soil grown system in Ladakh region. For the first time hydroponic systems were demonstrated in high altitude cold desert conditions for growing leafy greens and should be promoted in areas with scarcity of water and aerable land for successful production of nutrient rich vegetables.

The Spinach seedling age and seasonal ($p < 0.05$) substantial variation in plant development and morphology and yield attributing characters in 30 days old seedling in month of July in circulated hydroponic system compare to all seedling ages and season. The lettuce seedling age and seasonal ($p < 0.05$) substantial variation in plant development, morphology and yield attributing characters in 25 days old seedling in month of June in circulated hydroponic system compare to all seedling ages and season. The Spinach and Lettuce seedling age and seasonal variations no-significant difference ($p < 0.05$) in leaf Nitrate, phosphate, sulphate and Magnesium contents characters in in circulated hydroponic system compare to all seedling ages and season. The spinach and Lettuce seedling age and seasonal variations no significant difference ($p < 0.05$) in leaf Zn, Fe, Mn and Cu contents in circulated hydroponic system compare to all seedling ages and season. The spinach and Lettuce seedling age and seasonal variations ($p < 0.05$) did not differ significantly Leaf Glucose, Fructose, Sucrose and Total Sweetness Index contents in in circulated hydroponic system compare to all seedling ages and season.

To study growth and yield attributing parameters of spinach grown under in circulating hydroponic technique under greenhouse, open environment and room conditions. The crops grown Spinach and lettuce exhibited significant improvement in leaf area, height, root length, leaf count, and fresh weight of the plant and yield in NFT system with greenhouse compared to other conditions. The higher content of Calcium, Magnesium, Nitrate, phosphorus, sulphur: B, Cu, Mn, Ni, Zn and Fe elements and Glucose, fructose, sucrose and total sweetness index (mg.100g⁻¹ Fresh leaf) was observed in hydroponically grown spinach and lettuce especially in NFT system with greenhouse compared to other conditions.

The development of hydroponics around the world has improved fertilizer management and increased production of leafy vegetables. Vertical hydroponics promises to be the technology of near future in India where people in urban areas can also grow their own crops for consumption with limited space and free from any toxic chemicals and pesticide residues. Early harvesting also

can be achieved in hydroponics technology system means a greater number of crops per year can be grown efficiently. About 70-80% of water can also be saved by this hydroponics technology. Given that short-term crops like vegetables may be grown year-round in small places with little labor, hydroponics can be very helpful in India. in dry temperate Trans Himalayan region of Given that short-term crops like vegetables may be grown year-round in small places with little labor, hydroponics can be very helpful in India. where soil and water is limiting factor for agriculture production. Accordingly, the present investigation was directed to determine the possibility of growing leafy vegetable in hydroponic systems every round the year in amplitude in the trans-Himalayan Ladakh region. This study was also designed to determine the effects of different hydroponic systems, seedling age and different growing conditional on growth, morphological characteristics, biomass yield and quality of spinach and lettuce.

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ABBREVIATIONS/ ACRONYMS

Ag.	Agriculture
&	And
AAS	Atomic absorption spectrophotometer
C	Carbon
CV	Coefficient of Variance
dSm ⁻¹	Deci Siemens per meter
°C	Degree centigrade
EC	Electrical conductivity
Fig.	Figure
FAO	Food and Agricultural Organization
g	Gram
>	Greater than
ha	Hectare
kg	Kilogram
kg ha ⁻¹	Kilogram per hectare
<i>M</i>	Molar
Max.	Maximum
m	Meter
mg kg ⁻¹	mega gram per kilogram
min	Minimum

mm	Milli meter
'	Minutes
<i>viz</i>	Namely
N	Nitrogen
<i>N</i>	Normality
No.	Number
ppm	Parts per million
%	Per cent
K	Potassium
P	Phosphorus
S	Sulphur
pH	Soil reaction

Temp.	Temperature
TPF	Triphenyl Formazon
t ha-1	Tonnes per hectare
USDA	United States Department of Agriculture
Vol.%	Volume percentage
vs	Verses
ZnSO ₄	Zinc sulphate
EDTA	Ethylene diamine tetra acetic acid
<i>et al.</i>	And co-workers
DMRT	Duncan's multiple range test
LA	Leaf area

CHAPTER 1: INTRODUCTION

Hydroponics is a cutting-edge method of growing plants in nutrient solutions with or without the use of an inert medium to offer mechanical and physical support, such as peat moss, sawdust, coir dust, gravel, vermiculite, rockwool, and coconut fiber, etc. The name "hydroponics," which literally translates to work on water, comes from the Greek terms "hydro" (for water) and "ponos" (work). The term hydroponics, which means growing plants with their roots suspended in water containing mineral (Macro and Micro) nutrients, was first used by Professor William Gericke in the early 1930s. In 1940, Purdue University researchers created the nutriculture system. Commercial hydroponics farms were developed in the 1960s and 1970s in Germany, the Netherlands, Iran, Italy, Japan, Russia, Arizona, Abu Dhabi, Belgium, California, the United States of America, and other nations (Sharma *et al.* 2018). According to the requirements of different plants, hydroponic control systems have recently been designed to automatically regulate the amount of water, nutrients, and photoperiod (Resh, 2012). Hydroponics is the method of growing plants without soil while keeping their roots submerged in nutritional solutions, according to a simple definition. In locations where soil and water are limiting factors for plant development, hydroponic technology is particularly helpful in addressing the difficulties of climate change. It also aids in production system management for effective exploitation of natural resources. In order to successfully produce leafy crops as well as other vegetables while conserving 70 to 90% of water, commercial hydroponic systems have been deployed all over the world (Sharma *et al.*, 2018). Leading nations in the globe for hydroponic technology include Israel, Canada, the Netherlands, Australia, France, England, and the United States. In order to successfully apply commercial hydroponic technology, it is imperative to create low-cost procedures that are easy to use and maintain, need less labor overall, and have lower setup and maintenance expenses.

Types of hydroponics systems

i) Continuous flow solution culture with circulating methods: a) Nutrient film technology (NFT). Nutrient layer approach (NFT) for Deep Water Culture (DWC): This approach maintains a continuous layer of water and nutrients along a channel's bottom. As a result, some of the roots develop below the water line and receive nutrients, while other roots grow above the water line and receive oxygen-rich air (Cooper, 1988).

ii) Static solution culture and non-circulating techniques: Root dipping, flood and drain systems, and capillary action techniques are only a few examples.

Method for dipping roots: The water that carries the precise nutrient solutions for plant growth is completely submerged around the plant's roots. The roots and the water are oxygenated with the aid of an air pump.

The benefits of hydroponics

- There is no possibility of soil-borne disease, bug or pest infection to the crops when using the clean, simple hydroponic approach.
- Plants grow more quickly and take less time to mature than crops cultivated in fields.
- In regions where environmental stress (cold, heat, desert, etc.) is a major problem, the hydroponic approach is quite beneficial.
- Because crops are unaffected by climate change, they can be grown all year long.
- It is possible to do away with conventional farming methods like tilling, spraying, and weeding.
- When compared to conventional agriculture, hydroponics produces higher yields while using less water for irrigation.

The high-altitude, frigid desert regions of the Trans-Himalayas, which are located in northern India between 32° 15 and 36° latitude and 75° 15 to 80° 15 longitude. Located between 2550 and 7742 meters above sea level, the Indian union territory of Ladakh and the Himachal Pradesh district Lahaul and Spiti are distinguished for their rocky landscape. Its huge geographical area is 72976 km², and 13726 hectares of it are used for agriculture. 60% of the households have less than one hectare of cultivable land, despite the large geographic area. Double-cropping is only feasible in a small area that falls below an altitude of around 3500 m, hence single-cropping predominates. The Great Himalayan Range separates it from the Indian subcontinent, while the Karakoram Range borders it to the north. Extreme temperature swings, little rain or snow, powerful winds, a low plant population density, a thin atmosphere with intense UV radiation, and a delicate environment are all characteristics of the region. the wintertime temperature ranges of +35 to -35 °C. Irrigation is the only method used for agricultural production. Since rivers in the area are underutilized for agricultural purposes and glaciers are the primary supply of water for irrigation, this area could be used for hydroponic farming. There is virtually little knowledge of the many soil types among the

local farmers, despite the fact that the high-altitude, cold desert trans Himalayas regions exhibit a very broad range in texture, including sandy, loamy, silty loam, etc. and crops perform differently in each type of soil (Gupta *et al.*, 2017).

This region reveals that nutrient index of organic carbon and available potassium falls under medium class and available phosphorus falls under low class in the soils of while organic carbon and available phosphorus fall under medium class and available potassium under high class of nutrient index in soils. In view of the above it is concluded that the intensive soil management practices are required in the region of improvement in crop productivity and soil health (Dwivedi *et al.*, 2005). Production of unique natural resources such as crops remain limited due to water scarcity and poor market linkages due to its unique climatic conditions, there is glut of farm produce in August and September, while there is no availability of fresh fruits and vegetables during the rest of the year domestic food production is unable to meet the demand of the increasing population in the this area. Himalayas Regions gets approximately 73% of its food grain from outside the region. The total cropped cultivated area of Trans Himalayas area is only 0.2% of the total geographical area is under. Wintertime sees a dramatic decline in fresh vegetable supply, leading to an imbalanced diet. Micronutrient deficiencies are common in the area, including a deficiency of vitamin A, B6, B12, and folic acid. Micronutrient deficits are caused by seasonal shortfalls and a homogenous diet throughout the local population, a condition known as "hidden hunger." Food self-sufficiency is a crucial concern for the area. In this area, it is challenging to bridge the gap between the required amount and the amount of locally produced food.

Highly permeable immature coarse textured soil with low water holding capacity and poor available nutrient is one of the limiting factors for agriculture production. Due to the inaccessibility of the region and tribal farming systems being followed, the latest technology interventions are not able to reach the farming community (Dame *et al.*, 2019). For novel hydroponics crop production techniques along the height gradients of this chilly desert high-altitude location, consult an agricultural scientist.

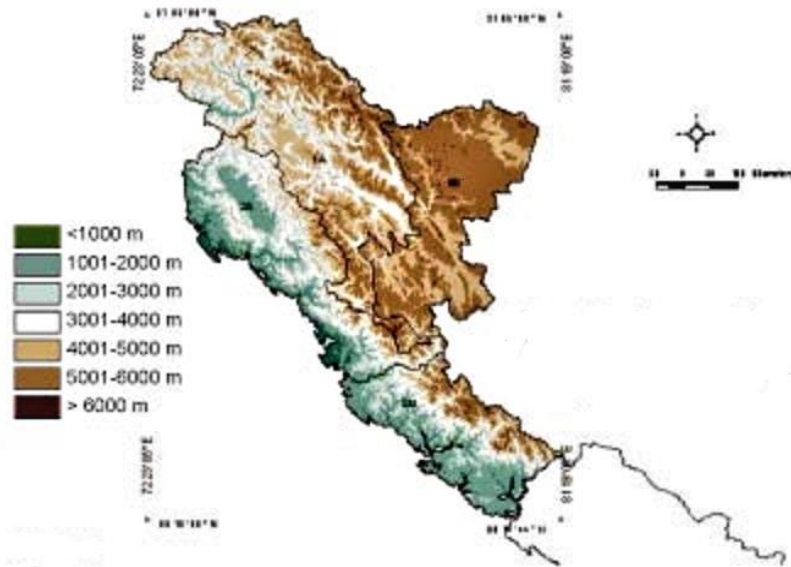


Fig -1.1 Trans Himalayas High-Altitude Cold Desert Regions of India. Source- (Arora *et al.*, 2010)

Lettuce (*Lactuca sativa*) is an important supply of vitamins K and A, with higher concentrations of the pro-vitamin A and β -carotene, as well as excellent source of folate and iron (Source: FAO). Lettuce mostly consumed as with burger and extremely demanding in hotels and restaurants as fresh salad. Lettuce is mostly used leafy vegetables that can be simply grown in commercially hydroponic system and mostly grown using the nutrient film technique (NFT) Hydroponic vertical farming helps to increase per unit area production (Touliatos *et al.*, 2016).

As a leafy vegetable that can be eaten, spinach (*Spinacia oleracea*) has leaves that can be eaten fresh, frozen, canned, diced, or dehydrated. When spinach is utilized fresh, frozen, steamed, or briefly boiled, it has a high nutritional value. It is a good source of iron, folate, magnesium, manganese, vitamin A, C, and K. The nutrients riboflavin and pyridoxine, vitamin E, calcium, potassium, and dietary fiber are all abundant in spinach. (Source: FAO and Aires, 2018). Growing of leafy vegetables through hydroponic technique has advance cultivation practise compared to soil, like early maturity (marketable yield) and uniform development of plants. Consequently, the area presents significant obstacles to the year-round production of fresh vegetables. Hydroponic technology can be an alternative to grow vegetables in the region round the year and this technology never been used in this cold desert region for growing crops (Jones, 2014). Considering the significance of hydroponic cultivation of high value crops the research proposal has been drafted with following objectives:

1. To study growth and yield attributing parameters of spinach and lettuce grown under hydroponic systems and soil cultivation.
2. Comparative evaluation of bio-chemical and mineral nutrition parameters of spinach and lettuce grown under hydroponic techniques and soil grown system.
3. To assess effects of seedling age and seasonal variations on yield and quality of spinach and lettuce in vertical circulated hydroponic system.
4. To study yield and quality parameters of spinach and lettuce grown in vertical circulating hydroponic technique under greenhouse, open environment and room conditions.

Hypothesis:

Worldwide hydroponics technology effectively manages nutrients, increasing the production of green crops. Vertical hydroponics promises to be the technology of near future in India where people in urban areas can also grow their own crops for consumption with limited space and free from any toxic chemicals and pesticide residues. Early harvesting also can be achieved in hydroponics technology system means a greater number of crops per year can be grown efficiently. About 70-80% of water can also be saved by this hydroponics technology. Since short-term crops like vegetables may be grown year-round in small locations with little labor, so in India, Hydroponics can significantly contribute especially in dry temperate Trans Himalayan region where soil and water is limiting factor for agriculture production. Accordingly, the present investigation was directed to determine the possibility of growing leafy vegetable in hydroponic systems every round the year in amplitude in the Ladakh region. This study was also designed to determine the different hydroponic systems, seedling age and different growing conditional on growth, morphological characteristics, biomass yield and quality of spinach and lettuce.

CHAPTER 2: REVIEW OF LITERATURE

The experimental findings of various researchers on Evaluation of “Circulatory and Non-Circulatory Hydroponic Techniques on Yield and Quality of Spinach and Lettuce at Cold Desert Trans Himalayan Region of India” are reviewed as under: proposed work has been designed and developed after considering available literatures and has been described below:

2.1 Hydroponic Technique and Cold desert Trans Himalayas of India

With or without the use of an inert medium to provide mechanical support, such as gravel, vermiculite, rock wool, peat moss, sawdust, coir dust, coconut fiber, etc., hydroponics is a method of growing and producing plants in nutrient media, according to Sharma *et al.* (2018). Early in the 1930s, Professor William Gerick coined the term "hydroponics" to describe the process of cultivating plants with their roots suspended in nutrient-rich water. The name "hydroponics," which literally translates to water work, comes from the Greek terms "hydro" for water and "ponos" for labour. Traditional farming methods, as well as the growing urbanization and industrialization that are limiting the amount of arable land, are all having a negative impact on the environment. To sustainably feed the world's growing population, a sizeable amount of food must be farmed utilizing novel methods. Changing the growth medium can replace unsustainable production in order to save the scarce water and land resources. In the present scenario, soilless cultivation could be successfully introduced and employed as a replacement for raising wholesome plants, crops, or vegetables.

According to a thorough investigation of the soil in the villages of the Ladakh region by Dwivedi *et al.* (2005), the soil in these areas has low to medium levels of organic carbon and macro- and micronutrient availability. Potassium is a highly-regarded nutrient in the soils of the Ladakh region. As elevation drops, the soils in this area (from Leh to Kargil) become more productive. The majority of the soils in the village have a coarse texture and are sandy. The development of agricultural productivity and soil health necessitate intensive soil management practices; it is determined in light of the aforementioned.

A cold desert high altitude region of the Tran-Himalayan was the subject of an investigation by Charan *et al.* in 2014. Site I (one to eleven thousand ft), Site II (eleven to twelve thousand ft), and Site III (twelve thousand amsl) are the altitudes from which the soils were gathered in Leh Ladakh, an area of frigid desert at a high elevation in India. The physico-chemical characteristics of soil were examined. At site III, the percentage of sand in the soil was noticeably high, and it steadily decreased

as altitude was reached. Contrary to silt and clay, site I's concentration was high and significantly ($p<0.01$) reduced with elevation. Between all study sites, there was no difference in electrical conductivity (EC) or bulk density (BD) that was statistically significant ($p<0.01$). The highest pH, TDS, and CaCO_3 values, however, were found at site I, while site III had more soil organic matter (SOM). Conversely, there is a positive association ($p<0.01$) between sand and SOM and height and the clay, silt, and pH. The physico-chemical characteristics of soil in high, cold desert altitudes vary with height.

Bhan *et al.* (2015) the location doesn't typically experience weather of this scale and is a low-rainfall area on the leeward side of the Zaskar Range. Leh's daily and monthly precipitation data analysis revealed that July and August are the wettest months. Additionally, the assessment of yearly excessive rainfall events shows that 40% of all annual excessive events occurred at some point during the monsoon months of July, August, and September. Contrary to popular perception, this analysis has shown that the southwest Indian monsoon no longer reaches Ladakh. Recent heavy rainfall events have been linked to westward-moving cyclonic circulations in the centre of the troposphere above Tibet and Ladakh at some point in active monsoon situations, indicating that such structures are necessary to provide heavy to very heavy rains over this area. It has also been discussed and demonstrated that the orographic features of the region, which are typically thought to act as an obstruction to rainfall, may, in fact, be improving the rainfall connected with cyclonic circulations migrating westward inside the middle troposphere.

LHDC ORGANIVF, (2019) In the rural areas of Leh Ladakh, where nearly 70% of the population is directly or indirectly structured in this industry, agriculture is a way of life. Regardless of the size of the region, 62% of families have less than 1 hectare of cultivable land. Since double-cropping only thrives in confined places below a height of around 3000 meters, single-cropping predominates. Irrigation is entirely dependent on agriculture for production. The main source of water for irrigation is provided by glaciers, while the nearby rivers are still not fully utilised for agricultural purposes. Due to a lack of water and poor market connections, production of specific herbal sources like apricot, apple, and low-season vegetables is still constrained. Due to its unique weather circumstances, there is an abundance of agricultural food between August and September, but clean culmination and greens are not readily available throughout the rest of the year. The district's expanding population has greater food needs than domestic food production can meet. Leh imports around 73% of its grain for food from outside the area. About 67% of vegetables are dependent on imports, compared to 85%

of fruits. Therefore, food self-sufficiency is a major issue for the area. It is challenging to satisfy local demand through neighbourhood production. Products must be transported across the Himalayas, via 5300 m-high passes, from Manali to Leh (474 km) or Srinagar to Leh (434 km), in order to be imported into Ladakh. Since 10,223 Ha of the district of Leh are generally under cultivation, only 0.2% of the total land area is not under cultivation. Comparably, the area beneath the woods cowl is minuscule 0.064%. Additionally, the population of Ladakh is surprisingly expanding, just as the adjacent population and the forces stationed nearby. The majority of families only own a tiny amount of land; 49.4% of families own less than five hectares. Increased population puts pressure on available land for agricultural and water sources. Land value has increased to the point where returning to agriculture/horticulture manufacturing is no longer competitive with various developmental sports, primarily.

Arora *et al.*, 2010 the sector's newest mountain range, served the Himalaya, has some of the region's highest peaks. These mountains are widely regarded as the sector's water towers in addition to being wealthy repository of frequently precise biodiversity. The Himalaya, which covers 12% of India's land area, is India's most notable mountain range. The majority of rivers that flow out of the Himalaya through the northern Indian plains, providing millions of people with life-supporting infrastructure. The rich biological, ecological, hydrological, aesthetic, and sociocultural values of the Himalaya are well known. It has significantly influenced the South Asian cultures; many of its peaks are sacred, and both Hinduism and Buddhism respect nature and the natural environment.

Kaushal *et al.* (2022) revealed that the Trans-Himalayan high-altitude, bloodless, desert tract areas are located in the northernmost region of India, between latitudes of 32° 15 and 36° and longitudes of 75° 15 and 80° 15. Lahaul and Spiti, a region of Himachal Pradesh and UT-Ladakh in India, is known for its rocky terrain and ranges in elevation from two thousand five hundred and fifty to seven thousand seven hundred forty-two meters above sea level. Its geographical area is enormous at 72976 km², and its cultivated agricultural area is 13726 hectares. Despite the close proximity in terms of distance, 60% of the families have far less than one hectare of arable land. There, single-cropping prevails, with just a little area below an altitude of about 3500 meters being suitable for double-cropping. Agriculture only receives support from irrigation.

2.2 Nutrition value of Lettuce vegetable

Murray *et al.* (2021) lettuce is around 95 percent water, and as a result, nutrients are dispersed over a larger area of the plant structure. This is because the water content in lettuce effectively dilutes the

nutrients. Actually, many lettuce kinds don't seem to be lacking in nutrients; rather, the serving sizes of many salads and garnishes are too small to provide enough nutrition. While preparation greatly reduces their bulk and increases the amount that can be consumed, it also decreases the bioavailability of several common vitamins, including certain B vitamins and water-soluble vitamins.

Kim, *et al.* (2016). It has been determined that although lettuce is one among the crops that is most widely consumed worldwide, the value of its organic process has been underappreciated. Low in calories, fat, and metal is lettuce. It has a good amount of antioxidant, iron, folate, and fiber. A good source of various alternative health-beneficial bioactive chemicals is lettuce. Research on plant viruses in vivo has connected the bioactive compounds in lettuce to therapeutic, cholesterol-lowering, and anti-diabetic actions. The nutrient makeup and bioactive substances, however, differ amongst lettuce varieties. The most popular type of lettuce in word wide is crisp lettuce, It contains only a small amount of vitamins, minerals, and bioactive compounds. Leaf lettuce and romaine lettuce are additional dietary lettuces with B-complex vitamin contents comparable to other wealthy vegetable sources. Compared to uncolored lettuce, red-pigmented lettuce has higher levels of phenolic resin compounds. The nutritious content of baby lettuce was also looked at due to its improving quality. Baby unseasoned romaine lettuce had a high antioxidant content. This review described the composition and organic process value of many lettuce varieties, making it easier for producers and consumers to choose lettuce varieties with higher organic process edges.

Mou, (2009) We determined that lettuce may be a popular vegetable and is essential to pepoles diet and nutrition. More nutrients are lacking in iceberg than in leaf and coral varieties. The enclosure of its leaves during a head construction is responsible for the iceberg's decreased nutritional cost because the synthesis or absorption of the numerous nutrients is weight-dependent. In addition to varietal variations, environmental aspects like light-weight, temperature, season, cultural techniques, fertiliser treatment, and storage conditions also have an impact on the nutritional quality of lettuce. Nutrient concentration is also influenced by the plant's water content. Vegetables' increased nutritional value would increase nutrient intake without increasing consumption. Genotypic heterogeneity in germplasm hints at the possibility of genetically improving lettuce's nutritional value. However, the lack of analytical capacity in the majority of crop development projects often hinders breeding attempts for nutrition. Biotechnology has the potential to significantly raise the cost of lettuce's nutrients. The majority of the factors influencing the commercialization of transgenic lettuce could be advancements in transgene expression, public acceptance, economic and marketing

hurdles, issues with material possession, and risk assessment.

Koudela *et al.* (2008) The leaf lettuce cultivars Bergamo, Dubáek, Frisby, Lollo Rossa, and Redin were evaluated in biannual tests. Leaf lettuce (*L. var. crispata*) is a type of green vegetable. During the two trial years of 1998 and 1999, which functioned as the study years, the lettuce was cultivated during the three distinct seasons of spring, summer, and season. The contents of selected substances and weights of leaf rosette were ranged as follows: antioxidant (65 to 302 mg/kg), K (2,394 to 6,477 mg/kg), metallic element (39 to 223 mg/kg), atomic number 20 (200 to 755 mg/kg), Mg (110 to 413 mg/kg), fibre (4.98 to 12.22 g/kg), dry matter (59 to one hundred forty g/kg), nitrates (293 to three,817 mg/kg) and therefore the weight of leaf rosette (164 to 502 g). Tracheophyte was found to significantly affect Dry matter and the contents of K, Na, Ca & leaf rosette weight. With the exception of fiber, the season had a significant impact on all the tested compounds. All the studied factors were impacted by the cultivation year except Ca. The findings suggest that tracheophyte, in addition to season and year, had a significant impact on the contents of chemicals under observation.

Kim *et al.* (2016) the nutritional makeup of two of the most consumed lettuce varieties in Western diets crisp head 'Iceberg' and cos lettuce with red or green leaves that were raised under typical farming circumstances and harvested at a similar biological process stage, were examined for their nutritional composition. Cos lettuce had more insoluble fiber than crisp head lettuce among the lettuce cultivars under investigation. Omega-3 unsaturated carboxylic acid -linolenic acid predominated as the main fatty acid and was more abundant in cos lettuce than crisp head lettuce. Cos lettuce included significant amounts of iron and minerals (Ca, Mg, and Mn) that are good for the bones. Cos lettuce (668.3 3 g-1) had a carotenoid and beta-carotene concentration that was 45% higher than that of crisp head (457.3 3 g-1) by dry weight. Red cultivars provided higher levels of minerals (Ca, P, Mn, and K), total carotenoids, total anthocyanins, and phenolics as compared to cultivars with less experience. Supporting our study's findings, cos lettuce was frequently richer in the nutrients examined. Red cos lettuce in particular had a significantly greater concentration of total carotenoids, total anthocyanins, and phenolics. Therefore, types of cos lettuce with red leaves as opposed to green ones may offer higher nutritional options.

2.3 Nutrition value of spinach vegetable

El-Sayed, (2020). It has been suggested that spinach fine powder may be an intelligent source of macromolecules, fiber, inhibitors, and minerals, making it a suitable ingredient to be used in the preparation of foods with high organic process or biological qualities. Spinach's fiber, mineral, total

synthetic resin, and inhibitor activity levels were all increased by adding more spinach nano powder with retentate. Furthermore, after four weeks of cold storage, the total solid, macromolecule, and acidity contents hyperbolic significantly, with the hyperbolic proportion of accessorial spinach nanopowder reaching the highest values

Miano, (2016). The biological process impact of (*Spinacia Oleraceae*) on human health by intensifying it in to numerous forms as raw or sauteed prevents one's health from numerous diseases anemia, and it also contains several malignant tumor agents. It also has anti-inflammatory properties and omega 3 fatty acids. In conclusion, incorporating spinach into our diets is crucial for protecting our health from a variety of diseases. A strong natural inhibitor mixture has been known to come from spinach leaves have been discovered to have a potent natural inhibitor combination. At least one physiological agent is inhibited by all drugs their dietary invention is very important to humans because of their antioxidative impact. All substances have an inhibitory effect on at least one bodily agent. It has been proven that consuming fresh, uncooked veggies helps to keep people healthy by preventing a number of ailments.

Roughani & Miri (2019) the Chenopodiaceous family includes the annual herb spinach (*Spinacia oleracea*). It is a cosmopolitan plant with South-West Asian roots that is grown as vegetables all over the world due to its great nutritional value. In appropriate proportions, spinach may also contain the minerals (iron, copper, phosphoric acid, zinc, selenium), B-complex vitamins (niacin and folic acid), antioxidants, carotenoids (β -carotene, lutein, zeaxanthin), phenols (flavonoids, p-coumaric acid), apocynin, and Omega-3 fatty acids. It is a rather quick-growing, low-maintenance vegetable that is distinguishable by both its bright green color and by its sleek, rectangular-shaped leaves, which can be either smooth or crinkly. The entire plant is utilized in traditional remedies for a variety of therapeutic benefits since it contains biological tannins and phenoplast active phytochemicals like alkaloids, flavonoids, steroids, glycosides, and terpenoids. Asthma, polygenic disorder, leprosy, urinary tract infections, inflammation of the respiratory tract, joint pain, thirst, raw throat, scabies, vomiting, ringworm, painful eyes, colds, sneezing, fever, and therefore diseases of the brain and heart are among the illnesses it is used to treat.

Tewani, *et al.* (2016). Man is said to be a frugivorous being, and a frugivore is typically defined as someone who only eats fruits and occasionally vegetables. There are several significant arguments in favor of giving leafy vegetables the top spot in the study of human existence. In a sense, the leaf serves as the plant's laboratory. Almost everything needed by completely unrelated parts of the

facility is manufactured here. *Spincia oleracea* Linn. (Family: Chenopodiaceae) is its scientific name. Spinach is utilized as food and also offers health benefits. Spinach is a powerhouse of minerals like magnesium, manganese, iron, metallic element, and folate, as well as vitamins like vitamin A, vitamin B, antioxidant, and vitamin E. The pigment in spinach helps to speed up digestion. Essential organic molecule, iron, vitamin A, and folate are the main chemical components of spinach. Daily use of recent spinach supplies the required amounts of iron, A, and folate. The bulk of vitamins are found in leaves, which are also the richest source of carotenoids, carotenoid, and xanthophyll. Carotene from it is where we frequently acquire A. Additionally, they are one of the greatest sources of iron and contain the majority of the minerals. In reality, by supplying the organic component supermolecule ingredients that cereals are lacking, leafy vegetables and dotted cereals enhance the supermolecule quality of the latter.

Agarwal *et al.* (2017) examined the inhibitory characteristics, DPPH free radical scavenging activity, and proximate composition of the binary compound extract of *Brassica oleracea* and *Spinacea oleracea*. The study found that, at the 0.05 level, the crude fiber, protein, iron, and calcium contents of *Brassica oleracea* were significantly higher than those of *Spinacea oleracea* by forty first, 41.6%, 8.7%, and 37.23%, respectively. In comparison to *B. oleracea*, *S. oleracea*'s binary compound extract had higher levels of total phenols and total flavonoids, measuring 41.20.18 mg GAE/g and 20.401.23 mg QE/g, respectively. The amount of inhibitory components in each leaf extract was moderate, but the radical scavenging activity of *B. oleracea* leaves was higher than that of *S. oleracea* leaves (IC₅₀ -26 g/ml) and *B. oleracea* leaves (IC₅₀ -48 g/ml) when compared to a simple water-soluble vitamin. The study may have found that, with the exception of its biological process essence, *Brassica oleracea* leaves are nearly as good as *Spinacea oleracea* leaves for inclusion in food formulation as therapeutic agents.

2.4. Hydroponic technology for quality production of Lettuce

Song *et al.* (2020) ascertained light and nutrients are essential for the growth of vegetables in greenhouses or plant factories. For the investigation of lettuce quality and growth in a growth chamber, a total of 12 treatments with a combination of 4 candlepower (150, 250, 350, and 450 mol m² s⁻¹) and 3 nutritional resolution concentrations (NSC) (1/4, 1/2, and 3/4 strength NSC) were established. Significant effects on chemical action pigment, biological process quality, mineral content, and inhibitor capability were seen when solar intensity and executive agency were combined. It was evident in lettuce treated with 350 mol • m² • s⁻¹ 3/4NSC and 450 mol • m² • s⁻¹ 1/4NSC and

higher candlepower were quickly accessible. In lettuce treated with 250 and 350 mol • m² • s¹ 1/4NSC or 3/4NSC, greater concentrations of soluble macromolecule, vitamin C, soluble sugar, and free organic compound were observed. Lower total N contents were also present. The amount of total P and K in lettuce doubled and bated, respectively, with rising executive agency and semiconductor diode irradiance. The very best and lowest total Ca contents were discovered in treatments of 150 m², s¹, and 1/4 NSC and 450 m², s¹, and 1/4 NSC, respectively. Better total Mg and zinc contents were discovered under treatments of 250 m², s¹, and 1/4 NSC and 150 m², s¹, and 3/4 NSC, respectively. Increases in executive agency level typically result in a bating of the inhibitor contents. 350 mol/m²/s/1 1/4NSC treatment on lettuce resulted in lettuce with the highest inhibitor concentration and capacity. In a plant industrial plant, the interaction of 350 mol m² s¹ 1/4NSC would be the ideal one for lettuce development.

Buchanan & Omaye (2013) investigation experiment was to determine whether lettuce that was grown entirely hydroponically had an equivalent level of antioxidants and vitamin E to lettuce that was grown in the ground. Among the four lettuce varieties examined were Waldmann's Dark Inexperienced, Red Lollo Antago, Red romaine lettuce Annapolis, and Butterleaf. In comparison to soil-grown lettuce, the vitamin E content of Waldmann's Dark Unexperienced, Red Lollo Antago, and Red romaine lettuce Annapolis cultivated hydroponically was 229%, 497%, and 492% greater. Antioxidant levels were 93, 171%, and 216% greater in Waldmann's Dark Inexperienced, Red Lollo Antago, and Red romaine lettuce Annapolis, respectively, than in their soil-grown counterparts. Horticulture may be a potential option for growing wholesome fruits and vegetables because lettuce cultivars that are fully produced hydroponically have substantially higher antioxidant and vitamin E levels than their soil-grown counterparts.

Sularz *et al.* (2020) the bio fortification of plants with minerals and vitamins has become one of the only methods of boosting nutrition. To assess the impact of iodine bio fortification on the chemical makeup of lettuce cv. "Melodion." The NFT hydroponic system was used to cultivate plants. Comparison of the effects of iodine fertilization on the fundamental chemical composition, fatty acid profile, macronutrients, concentration of sugars, nitrogenous compounds, chlorides, and iodine compounds, as well as macro and micronutrients. The findings of this study suggest that the application of iodine compounds has the ability to concentrations of a few micro- and micronutrients are greatly impacted by iodine fortification. Additionally, compared to manipulation and other therapies, the 3.5-diISA software decreased the attention of nitrates. As a result, it can be assumed

that the production of lettuce reinforced with iodo salicylates merits consideration given the fact that it can be a significant source of iodine and other components in the human food.

Song *et al.* (2020) nutrient solution concentrations (NSC) and photoperiod's effects on lettuce's nutritional value, antioxidant levels, and mineral content. With the combination of photoperiod and NSC, the amount of photosynthetic pigment, mineral element, and nutritional quality has significantly decreased. Lettuce has been discovered to have the most leaves and plant weight below the aggregate of 18-0.25X. In the 15-0.25X treatment, more photosynthetic pigment was present. Higher quantities of loose amino acids, soluble protein, and diet C were related with lower nitrate levels, shorter photoperiod and NSC. A prolonged photoperiod and a decrease in NSC may favor soluble sugar content growth. Under the combined effects of photoperiod and NSC, general P, K, and Ca content exhibited comparable behavior, with improved content at 3/4 NSC below exceptional photoperiods. Lower total Zn and N concentrations have been seen under prolonged photoperiods. Additionally, increased antioxidant contents have been found in shorter photoperiods with heights below 12-0.50X. Generally speaking, 12-0.50X is likely the greatest method for cultivating lettuce with the highest nutritional content in a plant.

Li, *et al.* (2018) investigated various lettuce production techniques, including aeroponics, hydroponics, and substrate culture. The shoot and root boom, root properties, and mineral contents of lettuce cultivars were top-notch plant parameters. The results showed that aeroponics significantly advanced the foundation boom with much more root biomass, root/shoot ratio, and significantly greater overall root length, root location, and root volume. In contrast to hydroponics, however, the greater root booms no longer resulted in a greater shoot boom because to the limited availability of vitamins and water. It is possible to draw the conclusion that aeroponic systems are better for the production of expensive real roots plants

Kobayashi & Yamaji (2022) using nutrient solutions coupled with tap water (Control), UFB water, and both faucet water and calcium nitrate solution, investigated the impact of ultrafine bubbles (UFBs) on the growth of leaf lettuce marketed hydroponically. The distinction between the three therapies was then contrasted using the identical environmental and nutrient awareness factors. The shoot clean weights, dry weights, Zn, K, Mn, Fe, Cu, Ca, and Mg concentrations, as well as the overall amount of nutrients, were all measured after harvest. There was no difference between the STD and ORL treatments, although the shot clean and dry weights were better with the STD and ORL treatments than with the control. In comparison to the Control treatment, plant nutrient uptake

increased with the STD and ORL treatments. The ORL and STD therapies both result in different Mn uptake rates. The results demonstrated that plant boom advertising with inside the STD and ORL treatments was impacted by reactive oxygen species produced by applying UFBs. Additionally, UFB housing made it possible to provide essential vitamins.

Lei & Engeseth (2021). Have a look at how the shape, texture, antioxidant capacity, and usefulness of lettuce produced hydroponically and in the soil were compared. For 35 days, giant caesar lettuce is cultivated in hydroponic or soil structures created in a laboratory. Hydroponically produced lettuce had roots that were noticeably ($p < 0.05$) longer, moister, and lower in ash. No appreciable variations in ascorbic acid, chlorophyll, carotenes, or total phenolics were discovered in freeze-dried lettuce. However, lettuce grown in soil had much higher levels of all chemicals tested based just on clean weight. On a dry basis (15.32%) and a wet basis (41.20%), lettuce's antioxidant capacity dramatically increased when grown in soil. Hydroponic lettuce had softer leaves and less susceptible midribs because of increased lignin (24.18%) in plant mobileular walls. This displays the complete increase. Consider demonstrating that lettuce grown in soil isn't always superior to lettuce grown hydroponically.

Lages *et al.* (2015). compared the land, water, and power needs of hydroponics to those of conventional farming. Theoretical records for hydroponic lettuce production were created using engineering equations that were filled with numbers from the literature, and they were compared to data from crop budgets and official agricultural statistics. In an 815 m² greenhouse unit, growing lettuce required 20 3.8 L/kg/y and 90 000 11,000 kJ/kg/y of water and energy, respectively (preferred deviation). In contrast, traditional manufacturing needed 3.9 0.21 kg/m²/y of produce to be produced with 250 25 L/kg/y of water and 1100 75 kJ/kg/y of energy. Hydroponics provided eleven 1.7 times better yields than conventional lettuce growing, but required 82 eleven times more strength.

Karimaei *et al.* (2001) valued and frequently used Hoagland's nutritional solution was contrasted with one that most suggested for lettuce's soilless lifestyle. The Massantini response was carried out in two strengths (full, 100%, and half, 50%). Before heading, the plants were collected, and the contents of N, P, and K as well as their ratios were measured. The effect of the Hoagland nutritional solution was the strongest, as determined by Massantini 50%. The contents of N and P in the lettuce plants on Hoagland were within the range of the lettuce DRIS (Diagnosis Recommendation Integrated System) guidelines. In the majority of cultivars, the relationship between growth rate, the highest number of boom features, and the concentrations of N, P, and K was adverse. Poor connection was found with

a few boom features, including leaf variety, leaf dry weight, and K content, according to solutions EC. The pH and EC of Hoagland's response were in line with those that were suggested for lettuce's soilless lifestyle. On all nutrient solutions, especially in Massantini 50%, the black seeded cultivar had more leaf variation than the others. The black seeded cultivar on Massantini 50% answer had the highest overall dry weight of leaves, however there was no discernible difference between this treatment and the Olimpo cultivar on Hoagland nutrient solution.

In a greenhouse, Sapkota et al. (2019) investigated the effects of several nutrient solutions on the weight and growth of lettuce cultivars grown in a floating non-circulated hydroponic apparatus. Two lettuce cultivars, Butter crunch and Black Seeded Simpson, were subjected to four different nutritional concentrations (N1), (N2), (N3), and (N4), respectively. The Butter Crunch cultivar and N3 remedy were much superior in comparison. For Butter Crunch and Black Seeded Simpson, respectively, the best sparkling weights were 115.33 and 93.17 g/plant inside the N3 feeding solution. Butter Crunch displayed the best glittering weight, leaf quantity, and leaf and root longevity among all nutritional treatments. A full-size fine dating with chlorophyll content for each cultivar was supported by the nitrogen content of the responses. It is anticipated that the development of a low-cost, easy-to-use hydroponic equipment will assist farmers in producing beautiful

Quy *et al.* (2018) studied the effects of EC focus points on lettuce growth, yield, and palatability in a vertical hydroponic system. Four replications of the Randomized Complete Block Design (RCBD) were used for the test. The EC ranges (0.5, 1.0, 1.5, 2.0, and 2.5 mS/cm) are covered by five remedies. The lettuce cultivars known as Rapid Red were tested. The seedlings had been moved beneath the vertical hydroponic structures two weeks following germination. For the duration of the entire period of development, the pH was kept between 6.0 and 6.5. It can be determined that nutrient solution concentrations (EC) have a significant negative impact on lettuce's growth, yield, and flavor when grown in vertical hydroponic structures. Yield suffered significantly ($P=0.01$) from EC ranges. The highest yield (27.5 t/ha) was obtained by the EC at 2.5 mS/cm, but there is no longer a significant difference at 2.0 mS/cm. For example, the highest concentrations of vitamin C and chlorophyll were found at 1.5 mS/cm of the EC level with inside the gift research. The lettuce cultivated in EC at 2.5 mS/cm is regarded as having a high level of good productivity.

Samarakoon *et al.* (2006) investigated the production of lettuce in hydroponic systems by maximizing electrical conductivity (EC) under warm (38.5°C) greenhouse conditions in Sri Lanka. In 50 L troughs, four blooms were developed with reduced dosages of Albert's response (0.5 and 1 g/l) compared to

the standard dosage (2 g/l). The EC of the 0.5, 1 and 2.0 g/l remedies were, respectively, 1.4, 2.0, and 3.0 dS/m. After stopping the early vegetative increase, the answers were adjusted daily for pH and replaced with fresh ones after a few weeks. Flowers were then gathered four weeks after transplantation. Both the sparkling and dry weights of flowers significantly decreased with an increase in the EC of the nutritional solution. 1.4 dS/m has a higher leaf creation rate (leaf number) than 2 and 3 dS/m, which results in increased sparkling and dry weights. Although they appeared to be within the same trend, other morphological characteristics including stem top and leaf position were no longer statistically significant. The intake of N, P, K, and Ca, on the other hand, significantly increased as EC increased. The most significant difference was between 2.0 and 3.0 dS/m. With the exception of P, the uptake charges of the other three ions were better or the same as they were during the late vegetative phase (the final two weeks). At the end of both the early and late vegetative stages, high amounts of each of the four vitamins in the final results revealed that nutrients were still available even below the lowest EC. The negative correlation between plant growth and yield and nutrient uptake rates is due to the harmful impacts of excessive nutrient uptake at the increased body structure inside the forms of toxicities, imbalances, or protective reactions. At Albert's reaction at EC of 1.4 dS/m (0.5 g/l) with complete substitution after weeks, it will be determined which fertilizer is best to use for producing leaf lettuce (*Lactuca sativa L.*) in a warm climate.

In order to determine the viability and acceptability of hydroponic cultivation as a prospective planting technique for greenhouse soil-based fully lettuce farming in temperate areas of northern India, Majid *et al.* (2021) undertook a study. Deep water culture and the hydroponic nutrient film method were evaluated in the current study and compared to the traditional soil-based growing approach in enclosed situations. The Tukey's multiple comparison test with a significance threshold of 0.05 was used to evaluate the efficacy of planting alternatives using three criteria: crop performance, water use, and the financial system. Deep water traditional method was discovered to be the most efficient for the period of the crop, producing a decrease with inside the plant increase duration by using 15 days. Additionally, the deep water conventional device's production and plant had been improved due to higher values for the majority of photosynthetic elements having been established within. The higher values of the best metrics, including chlorophyll, general soluble solids, protein, and crude fiber content, were used to analyze how the crop quality changed beneath the deep water culture system. Both hydroponic systems produced considerably better yields and more nutrient-dense output in less time when compared to the soil-based system (P 0.05). However,

in hydroponic circumstances, the dry matter content has significantly decreased. A huge 64% more water was saved using the nutrient movie method than with the alternatives. Financial evaluation indicators showed that both hydroponic methods outperformed soil-based methods overall, with benefit-cost ratios exceeding 2. Due to its simplicity, convenience of use, superior yield, financial viability, and nutrient-dense product, deep water tradition emerged as the strategy that holds the greatest promise for adoption beneath covered agriculture. The greatest and most sustainable alternative to traditional, soil-based lettuce production is hydroponic lettuce production.

Falovo *et al.* (2009) tested *Lactuca sativa* L. to see how different nutrient mixture concentrations (2, 18, 34, 50, or 66 mequiv L⁻¹) affected it at different times during the spring and summer growing seasons. It is grown in a floating system, variety acephala for its yield and attractive leaves. Marketable sparkling leaf area index, yield, total dry biomass macro element (Mg, N, P and K) contents, as well as the concentration of nitrate and total chlorophyll, all as a result of a rise in dietary supplement mixture. On an other hand, the root/shoot ratio and the total contents of glucose, fructose, starch, and protein decreased as a result of an increase in the concentration of the nutritional solution. Plants planted in the spring had less production (general leaves and dried biomass) in plants cultivated in summertime, they had better qualities of leaf (more carbohydrate and less nitrate concentrations). Although there may be a minor loss of some nutritional qualities, using 37 and 44 L⁻¹ of nutritional solution concentrations for the spring and summer seasons, respectively, may use inside this to maximize marketable sparkling production and minerals in leaves.

Kratky (2008) employed three non-aerated, non-circulated hydroponic growing techniques to investigate the effects of the between the nutritional solution and the tank cover, there is airspace on lettuce growth. Leaf lettuce called "Red Sails" (*Lactuca sativa* L.) in five-cm web pots, was cultivated that were supported by tank covers made of accelerated polystyrene bead board. The tank body supported the board and kept it in place as it floated in the nutritional solution. As the solution grew depleted, the board began to sink to a five-cm depth. Tanks that were 8.9 cm tall were used to store the 7.6 cm of non-circulating nutritive mixture. There was no additional dietary supplement added. Only 1.3 cm of the nutritional solution remained in the tank when the lettuce was removed. When the board remained stationary, head dazzling weights averaged 220 g over the course of seven vegetation in a year. Head weights decreased by 19% as the forums floated in the fertilizer solution throughout the crop. However, head weights barely fell by 7%, even though the forums originally floated at the nutritional solution and later rested on a five cm too-high guide throughout the last stage

of growth. It was advised to employ a higher rise rate between the nutrient solution and the accelerated polystyrene bead board tank lid in an area with high relative humidity.

Pelesco & Bontor (2016) studied explored head lettuce (*Lactuca sativa* L., *Asteraceae*) manufacturing in a non-circulating hydroponic machine below the climatic situations of Biliran, Philippines. One-pattern t-check turned into used to evaluate the experimental yield of head lettuce with the stated common yield of three kg/m² in lettuce developing regions of the Philippines below the traditional manufacturing machine. Result found out that the experimental marketable yield of 2.92 kg/m² is akin to the stated common yield of lettuce. Preliminary end result shows the opportunity of head lettuce manufacturing in a non-circulating hydroponic machine below the outside surroundings of Biliran, Philippines.

Ferguson *et al.* (2014) studied the differences in yield at high, medium, and low levels of commercial hydroponic nutrients in order to maximize the cost-gain dating inside the boom of green crops. Furthermore, we evaluated the viability of an organic self-organized nutrition solution for leafy green growth. The growth of leafy vegetables altered little in relation to the stage of commercial hydroponic nutrient solutions; however, the use of organic nutrient solutions produced complex leafy foods. In conclusion, we found that hydroponic systems are cost-effective and may support a long-term production of leafy greens. To develop more effective and economical organic nutrient solutions, more research may be needed.

Blasco *et al.* (2017) Hydroponic research was done to determine the effects of different doses (20, 40, and 80 IM) and types of iodine (iodate [IO₃⁻] and iodide [I⁻]) on the metabolism of carbohydrates and photosynthesis in lettuce flora. None of those treatments had a significant impact on the mechanism for sucrose production or its breakdown. The reduction in biomass and photosynthetic parameters (stomatic conductance and transpiration) seen after the application of 80 IM of I⁻ is likely responsible for the reduced rate of photosynthesis. This discovery supports the idea that using high dosages of I⁻ has a phytotoxic effect on plant physiology. As opposed to controls, all IO₃⁻ treatments enhanced the biomass of the flora, which was supported by higher rates of photosynthetic activity, stomatic conductance, and transpiration.

deSouza *et al.* (2019) performed an experiment to evaluate the growth of lettuce (*Lactuca sativa*) cv. 'Crocantela' in soil or a hydroponic system using measurements of vegetative growth, concentrations of chlorophyll, carotenoids, sugars, and starch as well as the dry mass (DM), sparkling mass (FM), variety of leaves (LN), and stomatal density. Due to the improved dietary conditions, particularly in

terms of macronutrients, hydroponically grown plants displayed significant variations in chlorophyll a (0.4481 mg/g), b (0.0.1233 mg/g), and general chlorophyll content (0.5714 mg/g), as well as more biomass when compared to plants grown in pots (FM: 342.60 g; DM: 21.13 g; NL: 17.75 g). The growth in carbohydrate attention and stomatal density in lettuce leaves was driven by the decline in water availability for flora grown in pots.

Mampholo *et al.* (2016). For combination effervescent reduction salads or as an entire product, lettuce evaluated the lettuce varieties grown in a closed hydroponic system based entirely on their morphological criteria, phytochemical content, and mineral content. The bioactive chemicals, shadeation values, and sparkling leaf mass for the sixteen lettuce varieties. The highest quantities of general phenols, flavonoids (isohamnetin, quercetin, kaempferol, epicatechin, mycertin, and anthocyanin), b-carotene, ascorbic acid, and higher antioxidant properties were found in Group 1; Multired 4. Leaf sparkling mass was also lower in this group. Group 2's results in terms of bioactive chemicals and sparkling leaf mass were somewhat better for the inexperienced lettuce varieties (Multigreen three and Multigreen 1) and the pink varieties (Cantarix, Lunix, Soltero, Veneza Roxa, Feska). The green lettuce varieties (Smile, Palmir, Hardy, Nasir, Monary, Atlantis, and Vera Green Frilly) in group three were confirmed to possess fewer bioactive chemicals and have greater leaf sparkling mass. Because they contain higher levels of phenols and flavonoids overall, red lettuce varieties are particularly rich in bioactive substances and antioxidant properties. For combined lettuce salads or as a whole product, Multired 4 (pink), Multigreen 3 (inexperienced), Multigreen 1 (inexperienced), and various pink lettuce varieties may be encouraged.

Shohael *et al.* (2017) conducted a test on lettuce production in hydroponic evaluation and soil culture for use in the hydroponics equipment, a balanced nutrient solution was incorporated inside the sparkling water. The lettuce blooms were supported on a Styrofoam board floating at the nutrient blend in a readily available plastic bowl in our non-circulating hydroponics system. Hydroponic lettuce production has been found to be more efficient than soil-based lettuce production. Maximum dazzling weight per plant received in a hydroponics system changed into 155.0 gm, as opposed to 148.0 gm for plants grown in soil at the same age. When compared to lettuce cultivated on soil, hydroponically grown lettuces have been found to have superior shape, flavor, and length. Fully developed lettuce bowls were brought to the dining table under low light for normal consumption after 32–35 days of subculture and lasted for an additional 7–10 days without changing its color, form, or flavor. In order to be highly practical and profitable for growing lettuce all over Bangladesh,

we therefore improved an easy to create and environment pleasant space to desk generation.

Frezza *et al.* (2005) out research to evaluate how well butter head lettuce grows in a soilless cultural system. The "Lores" variety of butter head lettuce was cultivated, and research was conducted on it. Floating machines (FS) and soil subcultures (SC) were compared in the first during the fall (autumn) manufacturing period [2002–2003], whereas in the second, a substrate subculture (PC) (plastic gutter packed with perlite) with three distinct calcium ranges (zero, three, and six me L⁻¹) within the nutrient solution was compared during the spring manufacturing period [2003]. Growing seasons vary according to the subculture machine. Although there have been significant variances in yield, flowers harvested from the soilless subculture generally displayed a drop in dry weight and leaf area. The production machine significantly reduced the material's nitrate content. Ascorbic acid content demonstrated that there were no treatment-related changes. During the two years of the test, a few versions of the floating machine effects were confirmed. Variations in inorganic cations, primarily K⁺ and Mg²⁺, have been discovered in plant harvest from all structures. Changes in color depth among manufacturing processes have been minimal. on lettuce cultivated on perlite, there was no variation in the occurrence of tip-burn with respect to particular calcium levels.

Touliatos *et al.* (2016) With lettuce (L. cv. "Little Gem") as a model crop, vertical farming structures (VFS), in which plants are grown in upright cylindrical columns, were compared to conventional horizontal hydroponic devices (HHS). Both structures had similar planting densities and root quarter extent. In a controlled environment indoor room with metal halide lamps providing artificial lighting, half-power Hoagland's solution was applied to perlite-grown plants. Each device's light yield (shoot sparkling weight) and distribution (photosynthetic photon flux density, PPFD) have been evaluated. While PPFD and shoot sparkling weight significantly decreased inside the VFS from top to bottom, the VFS produced more crop per unit of developing ground region than the HHS. Our results clearly show that VFS presents a desirable option for horizontal hydroponic boom constructions, and we recommend that adding artificial lighting fixtures inside the VFS will further boost yield.

Domingues *et al.* (2021) experimented on refers to the development of a device that is entirely controlled by software created in a laboratory. It shows the conductivity and pH over the course of a 24-hour period, across the entire manufacturing cycle. Additionally, allows for mechanical modification of any variation through solenoid valves that administer acid/base or nutritional solutions. The effectiveness of the suggested instrumentation was assessed by growing the same variety of lettuce (Vanda) simultaneously in various methods, with hydroponics in a greenhouse run

by cutting-edge technology serving as the reference. Industrial hobbyists have analyzed the agronomic and chemical parameters of each crop, demonstrating the early harvest (sixty-four to seventy-one days) with less labor, better management, and higher productivity, particularly in sparkling and dry depend of aerial parts, providing 267.56 and 13.33 g plant⁻¹ respectively, the use of advanced technology. The information gathered regarding the vitamins needed by the automatic hydroponic device was similar to that of the aforementioned researchers, and was as follows: K > N > Ca > P > Mg > S > Fe > Zn > Mn > Cu. This resemblance emphasizes the capability of changing the conductivity and pH parameters inside the instrumental device used to hydroponically produce lettuce, giving the maker a potent and practical chance.

Abu-Shahba et al. (2021) Experimented to Find the best gadget with the lowest cost and the highest production of low-water plant life by examining agricultural structures. Used three hydroponic systems: one without the use of bubbles (T1), one with the use of microbubbles (T2), one with the use of macrobubbles (T3), and one with the typical cultivation-based soil (T4). Plants produced in the microbubble hydroponic system had significantly higher levels of morphological characteristics, chlorophyll, phenol, flavonoid content, enzymatic and non-enzymatic antioxidants, mineral content, and dissolved oxygen. Additionally, compared to plants cultivated in specific hydroponic structures (T1, T2, and T3), plants grown in sand soil (T4) showed significantly higher concentrations of general soluble sugars, proline, and MDA. The findings show that less water is delivered into the hydroponic system than is used in sandy soil. Our research suggests that the hydroponic system can increase yields while using less water, so plants grown in hydroponic systems with microbubbles have superior plant growth, secondary metabolites, and antioxidants compared to plants grown in other structures.

2.5 Hydroponic technology for quality production of Spinach

Prosser *et al.* (2001) studied after a brief period while the S delivery became enough, the hydroponically grown spinach plant life was without an external source of sulphate. The course of events after this treatment was observed throughout time. The initial reactions have been found in the NO₃⁻ and SO₄²⁻-translocation and uptake processes. The impact was maximal full-size at higher [NO₃⁻] ext. for the former, which reduced with use of around 50%, whereas the latter increased six times over a four-day length. Growth inside the absence of exterior SO₄²⁻ resulted in the exhaustion of interior SO₄²⁻ pools, with the effects first becoming apparent in the roots, followed by younger leaves and, after a notable delay, mature leaves. Within the first two days of S deprivation, there had been a

substantial rise in $[\text{NO}_3^-]$ and arginine levels in younger leaves. In S-poor younger leaves, the awareness of glutamine, the amino acid that is most abundant in S-enough conditions, also more than doubled. Older leaves also showed changes in the levels of arginine, but the increase in glutamine concentration was no longer discernible. When results were expressed on a unit leaf basis, assays of nitrate reductase activity (NRA) and nitrate reductase (NR) mRNA from young leaves of S-replete and S-disadvantaged plant life revealed a divergence in interest and content only between days four and eight of the experiments. The precise activities (NRA:protein and RNA:protein) were preserved more or less unmodified, but there were also time-established changes inside the protein content. The results indicate that easier chemical composition analyses of younger leaves are a more sensitive way to assess the impact of S deficiency on N use than studies of NRA or NR transcript abundance. They further advise that a continuous supply of SO_4^{2-} - from outside the plant is essential for protein synthesis in immature leaves.

Janeczko *et al.* (2019) during a test, baby spinach was grown in accelerated polystyrene (EPS) plug trays in a bench size deep-water subculture (DWC) apparatus. There have been two experiments run. In order to compare the ability of an EPS tray designed with fewer cells but sown with more seeds per cell (to hold cover density), special seeding patterns, [1-2-1-2...] or [3-0-3-0...] seeds in line with sequential cell, on the same typical density in line with tray, were used. Utilizing this style of flat could reduce the need for producing substrate. When seeds were planted inside the [3-0-3-0...] sample, seed germination was reduced, although only by 5%. The weight of the harvested sparkling water decreased numerically but not statistically inside the [3-0-3-0...] sample. The second test revealed that the cultivars Carmel, Seaside, and Space were cultivated simultaneously. Carmel outperformed Seaside but no longer Space in terms of germination, coming in at almost 100%. Germination for Space ceased to be significantly different from that of the Seaside. Despite no longer being significantly different from Space, Carmel also had the best harvested sparkling weight; both places produced significantly more collected sparkling weight than the coast.

Öztekin *et al.* (2018) spinach grown inside a floating water subculture device was conducted in a greenhouse. Peat was used as a germination and rooting mixture throughout cultivation, which was carried out in aerated nutrient solutions on seedling trays. In trays with 210 cells (957 plant m^{-2}), each seed was placed into a separate hole (17 cc). Trays have been transferred to a climate-controlled greenhouse after germination within the germination chamber. The seedlings were moved to a water subculture on 07.12.2016 and 10.03.2017, respectively, for the first and second durations after

emergence. The three nutrient options were full dose, half of dose (with macro components decrease by 50%), and without nutrients (water). Three times in each period, plants' young leaves were picked. The findings showed that plant growth, yield, quality, and water uptake vary depending on the knowledge of nutritional response as well as the temperature throughout the growing period. Plant water intake, yield growth, and earliness have all been accomplished, particularly during the second period when temperatures were higher. It was found that diet C, leaf Ca content, and pH cost of the nutrient answer improved as awareness of the nutrient answer decreased, while leaf N, P, K, and Fe contents, EC cost of the nutrient answer, leaf nitrate concentration, yield, and plant biomass reduces. In many of the observed parameters, there was no longer a significant difference between full dose programs and half dose programs. The results show that spinach can be grown as a young leaf in a floating water subculture, and that in addition to lowering nitrate content, half-dose applications can be preferred in terms of yield and water intake.

Acharya *et al.* (2021) The growth response, yield, and dietary quality of lettuce and spinach grown in two different hydroponic structures—the circulated nutrient movie technique (NFT) device and the non-circulated device—have been studied and contrasted with open-field conditions used in traditional agriculture. Both lettuce and spinach showed significant increases in leaf area, sparkling weight, and yield under the hydroponics NFT system compared to the open field condition. Plant height, root longevity, and a variety of leaves per plant, however, no longer varied significantly across various treatments. In NFT and non-circulating devices, the lettuce production increased by 169 and 107%, respectively, while the corresponding growth in spinach increased by 109 and 124%. Hydroponically produced lettuce and spinach, particularly NFT system, were found to have significantly higher nitrate, phosphate, and sulphur content. Higher levels of soluble sugar in hydroponically grown lettuce and spinach suggest more high-quality output, which affects the attractiveness and crispness of leafy crops. Overall, the study suggests that the NFT hydroponics device is superior to other growing structures for quick harvesting, improved productivity, and very satisfying green vegetable production. Since the NFT gadget requires little space, it can be advertised in India's urban areas as a replacement for traditional farming.

Maneejantra *et al.* (2016) in order to maximize fertilizer control in plant factories, researchers carried out tests to determine the lowest macronutrient requirements of spinach with a preferred plant length. In a plant factory with temperature controls of 20°C and 17°C throughout the day and night, 350 mol•m⁻²•s⁻¹ of photosynthetic photon flux (PPF) for 12 hours each day, and 1,000 mol•mol⁻¹ CO₂,

spinach plants have been cultivated. After being transplanted to the study circumstances, spinach advanced quickly and took only 12–15 days to achieve its preferred marketable length. The target amounts of macronutrients per plant (90 grams of sparkling weight) at day 15 of cultivation under the treatment circumstances were determined to be 191 mg N, 31 mg P, 345 mg K, 34 mg Ca, 38 mg Mg, and 13 mg S. For hydroponic vegetable production in plant factories, a quantitative nutrient coping strategy with low nutrient concentrations is practical and resource-saving.

Ranawade *et al.* (2017) study comparing aquaponics, hydroponics, and conventional methods of growing spinach was conducted. Spinach was grown in soilless mixture, such as perlite and sphagnum moss. Media were employed to aid in the growth of the plant. Sphagnum moss and perlite media were taken from those media and used in hydroponics and aquaponics, respectively. This study was conducted to look at many morphological traits including height, germination length, ground location, yield of spinach, and biochemical evaluation such protein, carbohydrate, and chlorophyll content. The historically grown spinach had a higher height and surface area (Height: 23 cm; Surface Area: 79 sq cm) than the hydroponically and aquaponically grown spinach (Height: 18 cm; Surface Area: 70 sq cm; Height: 20.5; Surface Area: 72 sq cm) cultivated spinach. However, the germination length of spinach grown hydroponically and in aquaponic systems (4th day) was earlier than that of traditionally grown spinach (fifth day). When compared to traditionally grown spinach, which had a protein and carbohydrate level of 2.6% and 3.8, respectively, aquaponically and hydroponically grown spinach had a protein and carbohydrate content of 2.9% and 3.9. The maximum chlorophyll concentration was found in spinach grown traditionally (0.07%) and in spinach grown hydroponically and in aquaponic systems (0.06%). While historically and when grown hydroponically, spinach was given all of its nutritional needs from outside sources, however in aquaponics, vitamins were unquestionably provided by fish excrement. In hydroponics, the amount of nutrients needed is substantially less than in traditional techniques. In this study, guppy fish were used as a source of vitamins in aquaponic systems. The N, P, and K fertilizer known as 19:19:19 was used in modest amounts for hydroponics. In the past, fertilizers like urea, 19:19:19, and 15:15:15 were used to grow spinach. The yield of spinach grown in aquaponic systems was measured at 4455 kg per acre, which was much higher than the output of traditionally grown spinach (1615 kg per acre) and only slightly higher than spinach grown in hydroponic systems (3780 kg per acre).

Salamah *et al.* (2017) GIA13a was tested for its effects on Spinach and water spinach on altered Nutrient Film Technique (NFT) equipment supplied with Hoagland mixture. Hoagland Solution

contained the following nitrogen treatments: nitrate+GIA13a (NGia), nitrate without GIA13a (N), ammonium+nitrate (AN), ammonium+GIA13a (AGia), and ammonium without GIA13a (A). Two grams' inoculant were administered on the first and fourteenth days after planting (DAP). The experiment was completed 21 days after planting. Final result demonstrated physiological responses to presence of Nostoc sp. Gia13a in nutritional mixture varied between spinach and water spinach. The treatment with GIA13a inoculation, total spinach chlorophyll increased, whereas in water spinach, it decreased. Ammonium attention at the nutritional answer after a 14-day experiment showed that water spinach had a better ammonium intake than spinach. Additionally, Nostoc sp. Gia13a vaccination accelerated growth in water spinach shoots. In the trial, younger leaves of each plant exhibited the symptom of the chlorosis.

Nxawe *et al.* (2009) *Spinacia oleracea* L. growth rates at various irrigation water temperature regimes were determined within the greenhouse during eight weeks of hydroponic crop production. The water used to irrigate the spinach seedlings was heated to a variety of temperatures (24, 26 and 28°C). As a management tool, cold water from the faucet supplied by the fourth tank was used. Each bloom was given a combination of Ocean HYDROGRO and Ocean HORTICAL nutrition supplies that included all necessary components. Results showed that after eight weeks of growth, flowers grown at higher temperatures compared to the control flowers had superior leaf length (mm), leaf variety, and overall clean and dry weights (g per plant), with the best growth being reported at 28°C. These findings suggest that controlled spinach production during the winter months is feasible by employing irrigation with hot water in a greenhouse.

Gaikwad *et al.* (2020) during the wet season of the year 2018, a study of a test was conducted in Odisha. The ability to grow spinach using various hydroponic systems was investigated. Different hydroponic systems, such as the A-Frame hydroponics device and enhanced trays hydroponics device, have been developed for the growth of leafy vegetables. Three different types of development media, including sawdust, coco peat, and sterilized absorbent cotton, had been used. The response was applied as a medium of the liquid. Growth characteristics including seedling rate survival, length of the leaf, width of the lead, location of the leaf & clean foliage weight have been gathered. Outcome demonstrated parameter values of the physiological traits had been obtained to the greatest extent from flowers raised in sawdust inside the A body hydroponic construction. The majority of the time, plants produced in coco peat media were comparable to those grown in sawdust media, whereas flowers cultivated in sterile absorbent cotton inside the enhanced tray hydroponic system had the

lowest values.

Jeyasubramanian *et al.* (2016) Research in effects in particles in nanomaterials on sectors of the environment was proven to be of utmost importance. In this work, we examined the effects of iron oxide (Fe_2O_3) nanoparticle absorption in production rate on the spinach when applied hydroponically. Due to the incorporation of Fe_2O_3 , the experimental study measuring growth of the plant & dry matter evaluation. Vibrating pattern revealed analysis of the magnetometer a surge in spinach flora saturation magnetism as a result of Fe uptake. Additionally, a dose-structured ICP evaluation examined that iron concentration increases on spinach flora. Experimental investigation may provide fresh perspectives on the use of Fe_2O_3 nanoparticles in the agricultural industry.

Daniel *et al.* (2017) Spinach (*Spinacia oleracea* cv. Carmel) were grown in a traditional glass green house while receiving 3 exceptional nutrient solution treatments. The temperature and lighting conditions were same. For each of those 3 treatments, a replica trough device was provided using six growing structures. Each gadget has six trials collected over the course of a month. The 0.33 remedy became aquaponic (A7), obtaining that vitamins in tank of the fish using *Cyprinus carpio* aside from iron chelate. Two remedies from nutrients of hydroponics, from a remedy in negative log of hydrogen ion 7.0 (known as H7) and the opposite at pH 5.8 (H5). K_2CO_3 , KOH were added to hydroponic and aquaponic structures, respectively, to control the pH of the system. General yield, leaf floor location, elements of the tissue composition, then the weight of the dry to clean ratio of the have all been compared between treatments. In pairwise analyses of the various treatments, dry weight biomass yield levels were no longer exceptional. Similar to floor location effects, they were no longer exceptional across treatments. The key difference was that despite unbalanced and significantly lower than ideal nutrient contents inside the A7 condition A7 produced is increase as H5, the traditional pH with a full solution of the inorganic.

With a view to study the “**Evaluation of Circulatory and Non-Circulatory Hydroponic Techniques on Yield and Quality of Spinach and Lettuce at Cold Desert Trans Himalayan Region of India**”. The information about the materials utilized and the techniques employed during the inquiry is provided below under the relevant heading.

3.1 Location of the experimental site:

The experiment was conducted at Vegetable Research Unit, Defence Institute of High-Altitude Research, DRDO, Leh-Ladakh (latitude, longitude, $34^{\circ}08'23''\text{N}$, $77^{\circ}34'21''\text{E}$. and Altitude 3333 meter). The detail of materials used and methodology adopted has been described below:



Fig 3.1. Experimental Site (India, Ladakh and DIHAR-DRDO, leh)

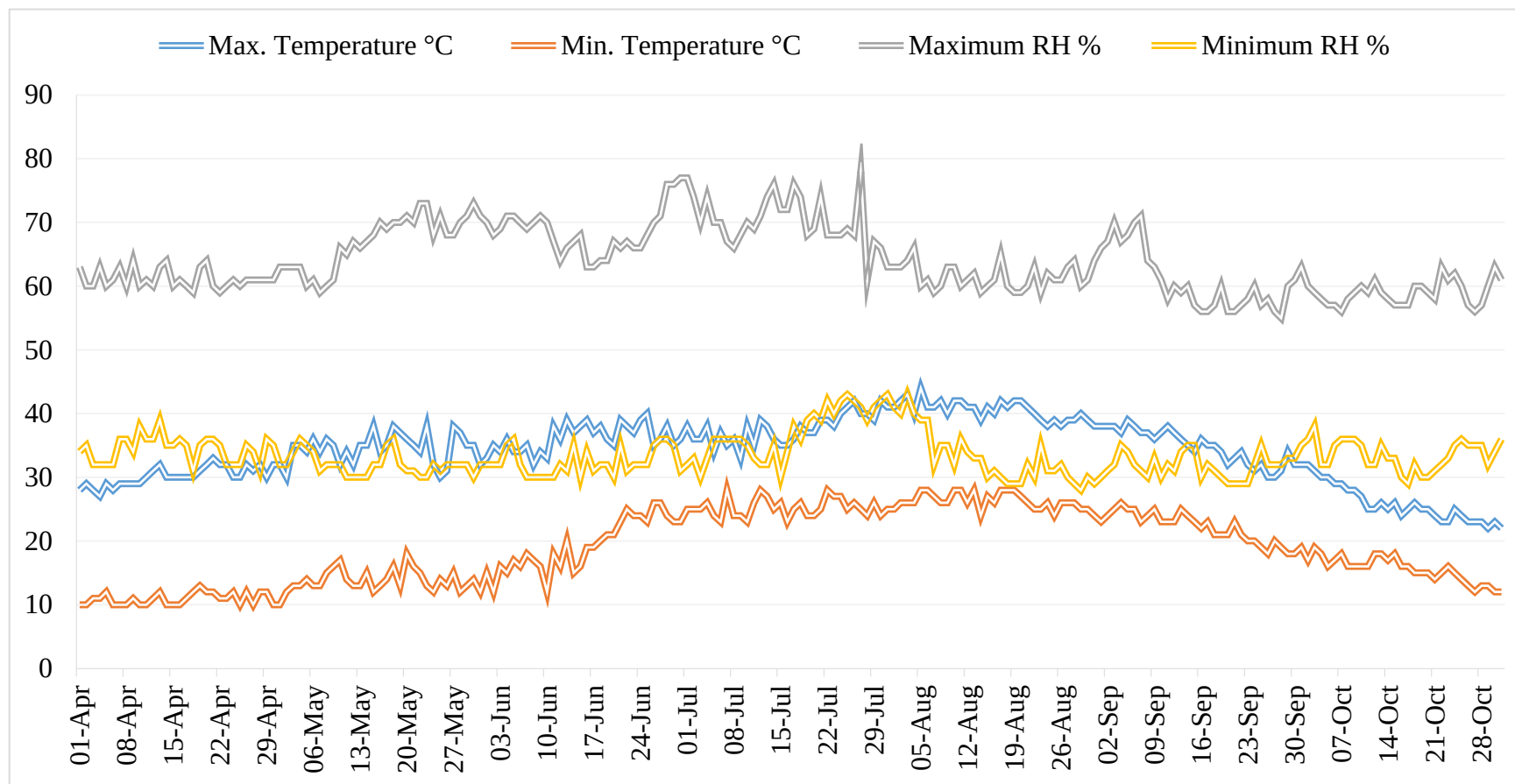


Fig 3.2 Average Agro-meteorological data in green house during experimental trial year 2018-2021

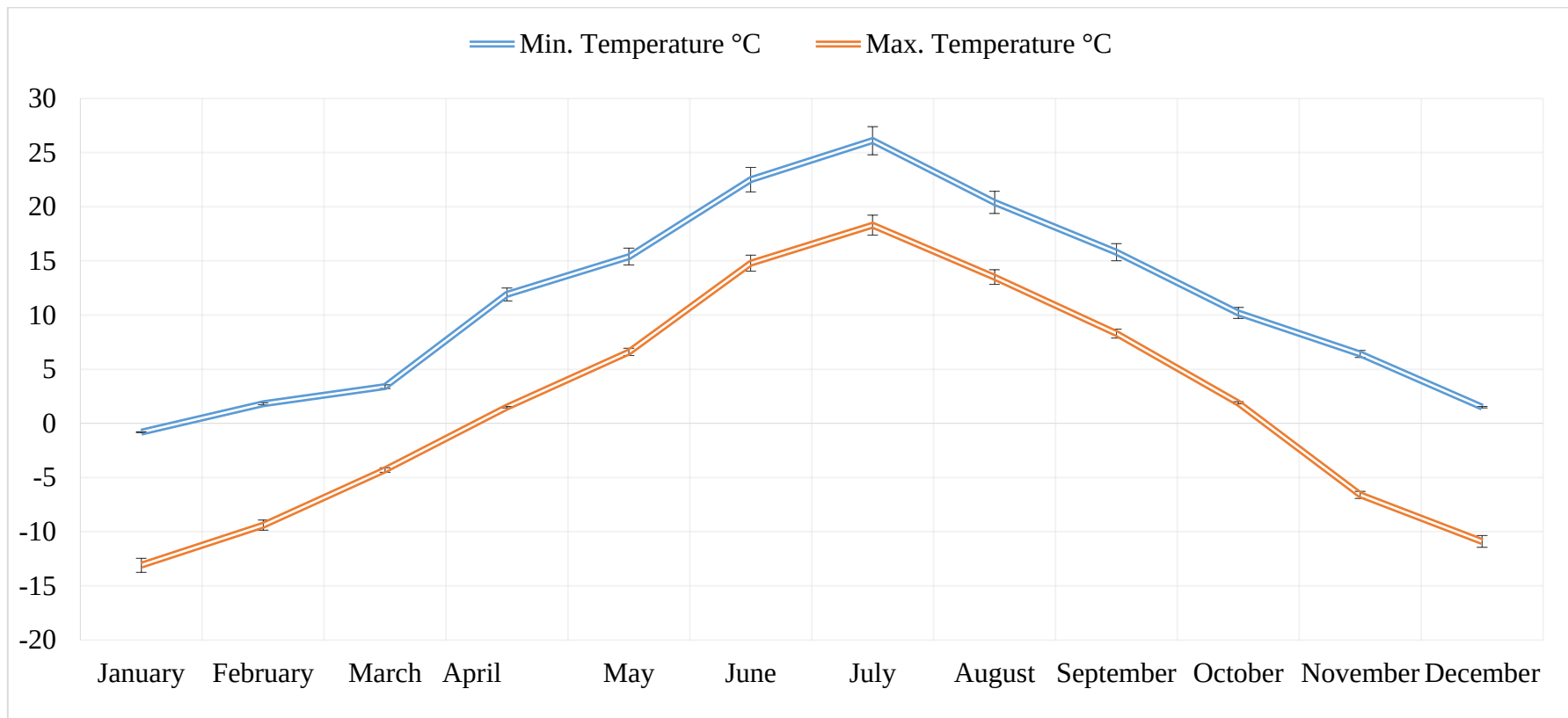


Fig 3.3 Average agro-meteorological data during experimental trial year 2018-2021

3.2 Agro-meteorological data during study period.

The standard meteorological period used to express the weather data collected throughout the inquiry are shown in Figs. 3.1 and 3.2 for the years 2018 and 2020, respectively.

3.3 Hydroponic systems.

The various hydroponic structures were specially designed for vegetables cultivation Dimension L×W×H like vertical circulated (160×90 ×150 cm with 46 net pot & reservoir of 20 lit capacity), horizontal circulated (140×60 ×90 cm with 28 net pot & reservoir of 20 lit capacity) and non- circulated (55×40 ×12 cm with 12 net pot & reservoir of 8 lit capacity cm) and in each net pot two seedlings were transplanted. Water is circulated through a submerged pump in the reservoir 8-10 litre per minute. In circulated system nutrient solution is pumped from the reservoir, circulated from upper layer to lower layer and excess solution is collected, replenished and reused in these methods.

3.4 Preparation of Nutrient Solution.

The majority of the plant nutrients utilized in hydroponics are inorganic and ionic forms that are dissolved in water. Using different chemical combinations, 17 essential elements were supplied that plants require for their growth (De Krei *et al.*1999). Hydroponics modified Hoagland nutrient solution (DIHAR-I and DIHAR-II) was preferably used for hydroponic cultivation of leafy vegetables. The nutrient solution preparation for leafy vegetable 2ml of each DIHAR-I and DIHAR-II nutrient solution was mixed with 1 liter of Tube well water and Fruits crops for up to flowering stage, 2.5 ml of nutrient solution was mixed with 1 liter of water whereas 5.0 ml of nutrient solution was mixed with 1 liter of water and used it during fruiting stage. A pH and EC meter (Hach, USA) was used to regularly test the pH and EC values of the hydroponics solution. For the best plant growth, the hydroponics solution pH ranges from 6.0 to 6.5. To bring the pH of the nutrition solution within the ideal range, NaOH and HCl were added (Trejo and Gomez 2012).

Table 1. Modified Hoagland Nutrient Solution composition

Component	Stock Solution (g/L)
DIHAR-I	
Ca(NO ₃) ₂ *4H ₂ O	202
Iron EDDHA (Iron Chelate)	5.6
DIHAR-II	
KH ₂ PO ₄	136
KNO ₃	133
MgSO ₄ *7H ₂ O	58.1
H ₃ BO ₃	2.89
ZnSO ₄ *7H ₂ O	0.22

MnCl ₂ *4H ₂ O	0.20
CuSO ₄ *5H ₂ O	0.08
NaMoO ₄ *2H ₂ O	0.12

3.5 Experimental Details.

3.5.1 Treatment Details.

3.5.1.1 Objective 1 and 2. In the present experiment, lettuce (var. Grand rapid) and spinach (var. Delta) were grown hydroponically and soil system under double layer polycarbonate greenhouse condition during summer season of 2018. During the experimental trial the minimum and maximum temperature was 18⁰C and 34⁰C respectively with relative humidity of 35-65% inside the greenhouse

Crops	Lettuce and Spinach	
Design	Completely randomized design	
Replication	3	
Objective	Comparative evaluation of growth and yield attributing parameters, bio-chemical and mineral nutrition parameters of spinach and lettuce grown under hydroponic techniques and conventional soil grown system	
System	Treatment No.	Treatment Name
	T1	Non-circulated System
	T2	Vertical NFT circulated System
	T3	Horizontal NFT circulated System
	T4	Soil Control System
Seedling Stage	3-4 cm (Transplanting to System)	
Month of study	Trial start	Trial harvest
	I st May	5 th June
	I st June	5 th July

3.5.1.2 Objective 3. The experiment, lettuce (var. Grand rapid) and spinach (var. Delta) were grown NFT hydroponically under double layer polycarbonate greenhouse condition during summer season of 2019. During the experimental trial the minimum and maximum temperature was 18⁰C and 34⁰C respectively with relative humidity of 35-65% inside the greenhouse.

Crops	Lettuce and Spinach	
Design	Completely randomized design	
Replication	3	
System	Vertical NFT circulated System	
Objective	To assess effects of seedling age and seasonal variations on yield and quality of spinach and lettuce in vertical circulated hydroponic system.	
Seeding Age	Treatment No.	Seeding Age
	T1	25 Days old
	T2	30 Days old
	T3	35 Days old
	*Treatment combination for April to October	
Month of study	Trial start (date)	Trial harvest (date)
April	20 March (25 DAS)	25 April
	25 March (30 DAS)	30 April
	01 April (30 DAS)	05 April
	*Treatment combination (25,30 & 35 DAS) for April to October	

3.5.1.3 Objective 4. The various experiment were conducted at Vegetable Research Unit, Defence Institute of High-Altitude Research, DRDO, Leh-Ladakh (latitude, longitude, 34°08'23"N, 77°34'21"E and Altitude 3333 meter) during summer season of year 2021. The average day length approximately 9-14 h; temperature, 5-34oC and relative humidity 30-85% during experimental trial. The experimental site was fairly uniform and levelled open window double layer polycarbonate greenhouse, open environment and room conditions with glass window north fessing. The type of hydroponics system nutrient vertical film technique (NFT) used for research trail.

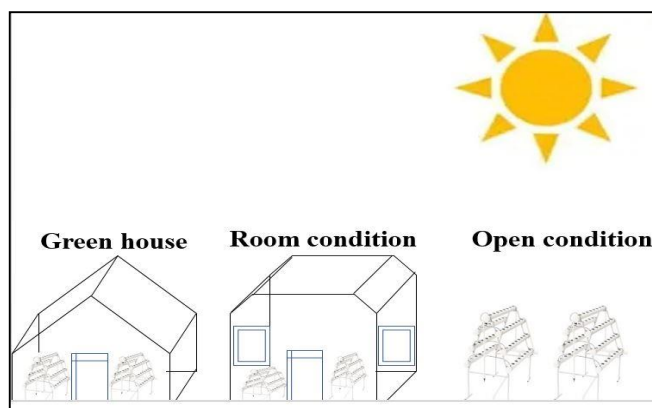


Fig. 3.4 : Diagrammatic representation of experiment (greenhouse, room and open environment)

Crops	Lettuce and Spinach	
Design	Completely randomized design	
Replication	3	
System	Vertical NFT circulated system	
Objective	To study yield and quality parameters of spinach and lettuce grown in vertical circulating hydroponic technique under greenhouse, open environment and room conditions	
	Treatment No.	Treatment Name
	T1	Green House
	T2	Open condition
	T3	Room condition
Month of study	Trial start	Trial harvest
	I st July	5 th August
	I st August	5 th September

3.5.2 Hydroponic culture practices:

Hydroponic system vertical circulated, horizontal circulated and soil condition were designed for the cultivation of Lettuce varieties grand rapid and Spinach varieties delta. The basic prior need for growing plants in hydroponic. Lettuce and Spinach seed to be grown; therefore, a mixture of Cocopeat, Vermiculite and Perlite (5:2:1) media for nursery in green house. These seedlings were ready to transplant in 4 leaf stage and uniform seedlings were transplanted in different hydroponic system and soil condition. The seedlings were placed into net pots in growing channels in hydroponic systems. The net pots were filled with clay balls for supporting seedlings. The nutrient solutions were added approximately at 10-12 days' interval in hydroponic systems. Leafy vegetables were harvested after 35 days after transplantation.

3.6 Observations recorded:

Sr. No.	Particulars	Method	Reference
Nutrient Solution			
1	pH	By using glass electrode pH meter	Jackson (1973)

2	EC (dSm ⁻¹)	By using conductivity meter	Jackson (1973)
3	Temperature(C ⁰)	Thermo-meter	Chamoun,M.(2005)
Growth and yield Parameters			
1	Plant height and root length (cm)	By using measuring scale	---
2	Leaf Area (cm ⁻²)	By using Leaf Area meter	---
3	Number of leaves	-	---
4	Yield per plant (g)	By using Weighing Machine	---
5	Yield per m ⁻² (g)	By using Weighing Machine	---
Quality traits Parameters			
1	Anthocynin content	Anthocyanin content meter	A.O.A.C (1990)
2	Chlorophyll content	Chlorophyll content meter	A.O.A.C (1990)
3	Anions	Ion-Chromatography	A.O.A.C (1990)
4	Carbohydrates	Ion-Chromatography	A.O.A.C (1990)
5	Macro and Micro nutrients	AAS and ICPMS	A.O.A.C (1990)

3.6.1 Nutrient Solution: pH & EC by using glass electrode pH& EC meter

3.6.2 Sample collection: Nine randomly selected plants were taken from each experimental site for plant height. At the time of transplanting plants were tagged. Recorded of growth, yield chlorophyll and parameter each system at harvesting time. Samples was collated, dry and storage in refrigerator for national quality analysis.

3.6.3 Plant height and Root length (cm): The height of plant will be recorded using measuring tape from the crown level to apex of the primary leaf. It will be measured in centimetres (cm)

3.6.4 Leaf area: The area of each leaf was measured using the Biovis PSM - L2000, Germany Leaf area meter Analysis System, employing the physiologically active leaves of each plant that were gathered.

3.6.5 Number of leaves: The number of leaves can be counted at the end of harvesting and the mean is expressed as the number of leaves per plant

3.6.6 Yield per plant (g): The weight of entire fruits harvested per plant will be recorded for each

cultivar and the result will be expressed as yield per plant.

3.6.7 Chlorophyll and Anthocyanin content: Chlorophyll and anthocyanin content in leaf were determined by portable chlorophyll and anthocyanin meter respectively (CCM-200 plus and ACM-200 plus, ADC Bioscientific, UK).

3.6.8 Anions and Carbohydrates: nitrate, phosphorus, sulphur, and sugar profile determination Using a tissue homogenizer (IKA, T10 basic ULTRA-TURRAX, Germany), 200 mg of dry, homogeneous lettuce and spinach leaves were taken and homogenized at 10,000 rpm in Type-I ultrapure water (DQ3, Millipore Waters, USA) for 2 min. The homogenized samples were then centrifuged at 10,000 rpm for 15 minutes and filtered through Whatman No. 1 filter paper after being sonicated in an ultrasonic bath (Ultrasonic cleaner YJ5120-1, India) at 400C for 30 minutes. The final diluted samples were then passed through a 0.22 µm microporous membrane filter with a 25 mm diameter after additional dilutions had been made. Ion chromatography (IC) equipment (930 compact IC Flex, Metrohm, Switzerland) was used to measure the content of nitrate, phosphorus, sulfur, and sugar profile (glucose, fructose, and sucrose). MetroSep A Supp 5-250/4.0 anion column was utilized for anion analysis (nitrate, phosphate, and sulphate), while RCX-30-7-m-250/4.1mm (Hamilton, USA) column was used for soluble sugar measurements. With a flow rate of 0.7 ml.min⁻¹, 3.2 mM Na₂CO₃, 1 mM NaHCO₃, and 5% acetone were employed as the eluent in the mobile phase, and 100 mM H₂SO₄ solution served as the suppressor solution for the anion analysis. 0.1M NaOH was employed as the eluent at a flow rate of 1.0 ml.min⁻¹ for the analysis of sugar. A conductivity detector was used to find nitrate, phosphate, and sulphate, while an amperometric detector found soluble sugars.

3.6.9 Macro and micro nutrients analysis of leafy cultivars: Utilizing AOAC (1990), the mineral content of the leafy sample was calculated. Methods. Using standard solutions (Sigma Aldrich) of the relevant elements, the concentrations of calcium (Ca), magnesium (Mg), manganese (Mn), iron (Fe), copper (Cu), boron (B), nickel (Ni), and zinc (Zn) were determined. Briefly stated, 8 ml of an acid mixture (6.0 ml nitric acid and 2.0 ml HCl) were used to first digest 200 mg of the material using a microwave (microwave digestion, Analytic Jena). After adding the acid mixture to the plant dry sample in the digestion flask and heating it, a clear digest was produced. Later, distilled water was used to dilute the digested samples to the 50 ml mark. After obtaining the digest, aliquots of the clear digest were utilized for atomic absorption spectroscopy (ZEEnit 700p, Analytic Jena, Germany) and inductively coupled plasma optical emission spectroscopy (ICPE-9000, Shimadzu, Japan), employing filters that matched the analyses different elements. The mineral concentrations in fresh green vegetables are mg per 100gm.

3.7 Statistical analysis: Statistical analysis was performed on all experimental data using SPSS 22

(SPSS Corporation, Chicago, Illinois, USA) Pallant J 2020 and MS Excel 2019. One-way analysis of variance (ANOVA) was used to assess differences between mean values. The Duncan's test was used to compare the differences, and a significance level of 5% was used.

The experiment entitled “**Evaluation of Circulatory and Non-Circulatory Hydroponic Techniques On Yield and Quality of Spinach and Lettuce at Cold Desert Trans Himalayan Region of India**” conducted at Vegetable Research Unit, Defence Institute of High-Altitude Research, DRDO, Leh-Ladakh. The results obtained related to the four objectives are presented and discussed under the heads’

4.1 Objective Ist and IInd. “Comparative evaluation of growth and yield attributing parameters, bio-chemical and mineral nutrition parameters of spinach and lettuce grown under hydroponic techniques and conventional soil grown system”.

4.1.1 Lettuce and spinach crops growth and yield attributing: The study of plant growth, morphology and yield attributing characters of lettuce and spinach grown in different hydroponic systems viz. vertical circulated, horizontal circulated and non-circulated system compared to soil is presented in table 1.

The lettuce crop result showed significant difference ($p < 0.05$) in plant height and yield per meter square in vertical circulated system compared to horizontal circulated, and soil system. Plant root length significant in horizontal circulated and non-circulated to other treatments. Vertical circulated, horizontal circulated and non-circulated system significant similar result in leaf per plant, leaf area and fresh weight per plant compared to soil. Whereas, plant height, leaf area, fresh weight per plant and yield per meter square of spinach was found significantly different ($p < 0.05$) in vertical circulated hydroponic system as other systems. Therefore, significantly similar result was found in root length and leaf per plant on both of vertical and horizontal circulated condition.

The lettuce and spinach plant height maximum to found plant height (26.0 ± 2.8 cm and 30.33 ± 4.92 cm) in Vertical circulated system followed by horizontal circulated system in spinach (26.11 ± 4.14 cm) and non-circulated system in lettuce (19.2 ± 2.7 cm). While leafy vegetable grows in soil system recorded minimum values for plant height in both crops. The root length exhibited highest values in horizontal circulated (21.6 ± 3.4) of the lettuce followed by circulated non-circulated system ($20.3 \pm 4.2b$) both found significant. Whereas, spinach crop exhibited maximum root length in vertical circulated system (28.11 ± 3.26) followed by horizontal circulated system (25.67 ± 5.87 cm) and lowest root length was recorded in soil system (9.78 ± 2.11 cm). Plant height of both crop was depending on supply of nutrient with air in to plant. The plant grows in hydroponics system supply sufficient quantity that why increase plant height in hydroponic condition. Similar result was observed by Li et al (2018)

and Chunli et al (2021).

The highest number of leaves per plant of lettuce (20.8 ± 2.3 and 19.3 ± 1.4) and spinach (24.56 ± 7.92 and 22.22 ± 6.65) was recorded in vertical circulated system and horizontal circulated system, respectively. Whereas, leaf area was found in vertical circulated system (lettuce 102.2 ± 9 cm² and spinach 88.89 ± 7.3 cm²) which was significantly higher ($P < 0.05$) than soil grown vegetables

The lettuce crop yield per plant in vertical circulated spinach (52.1 ± 9.2 g plant⁻¹), horizontal circulated (50.8 ± 9.6 g/ plant), and non-circulated (48.8 ± 10.4 g/plant), system exhibited significantly similar, whereas spinach grow in vertical circulated system (55.56 ± 5.9 g plant⁻¹), was significantly high ($P < 0.05$) significantly highest values compared to soil grown crops (Lettuce 28.2 ± 11.4 g plant⁻¹ and Spinach 38.49 ± 4.18 g plant⁻¹). The plant yields depending on root system was continuously sufficient nutrient solution in hydroponic system. Our results are similar with N. Ercan and R. Bayyurt 2013 and Ciriello et al 2019

The leafy vegetables yield gram per meter square was significantly high in vertical circulated system (Lettuce 3.2 ± 0.6 kg /plant and Spinach 3.57 ± 0.52 kg/ plant) followed by horizontal circulated and non-circulated system then soil grown crops (Lettuce 0.70 ± 0.3 kg plant⁻¹ and Spinach 0.96 ± 0.08 kg plant⁻¹). The growth and yield attributing of lettuce growing in hydroponic and soil both were much less as compared spinach crop. Leaf area and fresh biomass incurred significant interaction Pannico et al (2019), Kratky (2004) and Kratky (2010). Water conservation and increased output per unit area are two benefits of contemporary agriculture. Compared to normal farming, hydroponic crop cultivation increases fertilizer use efficiency and decreases water loss. Sapkota *et al.* (2019), AlShrouf (2017), Öztekin *et al.* (2018) and Ferguson *et al.* (2014)

Table 4.1: Lettuce and spinach crops growth and yield attributing in hydroponic systems and soil control.

Growing Conditions	Plant height (cm)	Root length (cm)	Leaf number plant⁻¹	Leaf area (cm²)	Fresh weight (g plant⁻¹)	Yield (Kg m⁻²)
Lettuce						
Vertical NFT	26.0c	18.1b	20.8b	102.2b	52.1b	3.2c
Horizontal NFT	18.3b	21.6c	19.3b	91.7b	50.8b	2.7b
Non-Circulated	19.2b	20.3bc	19.3b	87.6b	48.8b	2.6b
Soil System	14.8a	9.8a	16.4a	48.2a	28.2a	0.7a
Spinach						
Vertical NFT	30.33c	28.11c	24.56b	88.89c	57.57c	3.57c
Horizontal NFT	26.11b	25.67c	22.22b	77.67b	48.87b	2.64b
Non-Circulated	20.78a	21.00b	16.44a	69.22a	44.48b	2.4b
Soil System	18.67a	9.78a	15.67a	66.33a	38.49a	0.96a

Data were shown in mean $\pm$ standard deviation (n = 12). Statistics show that the values in the same column with various letter values are significant by Duncan's test at $p \leq 0.05$

4.1.2 Lettuce and spinach crops presence of anions and pigment contents: The Lettuce and spinach leafy vegetables data results show ($P < 0.05$) significantly effects on plant quality parameters anions contents like Nitrate, Phosphate and Sulphate grown in different hydroponic system and soil condition. On the other hand, growing conditions had non-significant effects on pigment contents of lettuce and spinach were influenced by different hydroponic system and soil condition are depicted in Table 2.

While analysing the quality attributes of leafy lettuce, vertical circulated exhibited the maximum nitrate content ($5416.7 \pm 686.7 \text{ mg kg}^{-1}$) and minimum content ($3669.3 \pm 384.9 \text{ mg kg}^{-1}$) was recorded in soil system. The highest nitrate content of spinach ($12488.7 \pm 1442.3 \text{ mg kg}^{-1}$) was recorded in vertical circulated system, though it was significant similar with), horizontal circulated system and the minimum nitrate content ($8040.4 \pm 223.1 \text{ mg kg}^{-1}$) was recorded in soil condition. In hydroponic cultivation in nitrate concentrations were significantly impacted by the nutrition solution concentration. Öztekin *et al.* (2018). The most frequent factor influencing plant development and production is nitrate content in the plant. The primary source of nitrate consumption for humans can be thought of as leafy greens. Ranasinghe and Marapana (2018) and Sularz *et al* (2020).

Similarly, ($P < 0.05$) significantly maximum values phosphate content ($9570.0 \pm 178.3 \text{ kg}^{-1}$) in lettuce was found in vertical circulated system and minimum phosphate content ($8094.8 \pm 224.7 \text{ mg kg}^{-1}$) was recorded in soil system. Phosphorus is a fairly prevalent component of vital life-sustaining chemicals that are found in leafy vegetables Oladeji and Saeed (2018). Likewise, highest sulphate content ($5867.4 \pm 588.4 \text{ mgkg}^{-1}$) was recorded in vertical circulated system after by horizontal circulated ($5003.2 \pm 164.2 \text{ mgkg}^{-1}$) and soil condition ($3710.6 \pm 112.2 \text{ mgkg}^{-1}$) in lettuce. Similarly, in spinach vertical circulated system exhibited highest phosphate ($9126.7 \pm 185.8 \text{ mgkg}^{-1}$) and sulphur content ($7055.3 \pm 136.1 \text{ mg kg}^{-1}$), While minimum phosphate ($265.4 \pm 45.6 \text{ mgkg}^{-1}$) and sulphate ($124.6 \pm 26.9 \text{ mg kg}^{-1}$) of spinach was recorded in soil condition. Overall, phosphate and sulphate content accumulation in higher in lettuce compare to spinach and nitrate content recorded higher in spinach v/s low in lettuce. Similar result recorded by Frezza *et al.* (2005) and Ezziddine *et al.* (2021) the production system compared to the soil had a considerable impact on the plant's primary and secondary nutrient content. In all hydroponic systems, the maximum amount of water, nutrients, and oxygen that plants could absorb was frequently below the requirements for the plant life cycle. Its helps to helping increasing nutritional quality of plant production (Blok *et al.* 2017 and Blok *et al.* 2017)

Table 4.2 Anions and leaf pigment contents in lettuce and spinach crops produces in hydroponic systems and soil control

Growing Conditions	Nitrate (mg kg⁻¹)	Phosphate (mg kg⁻¹)	Sulphate (mg kg⁻¹)	Anthocyanin content (ACI Unit)	Chlorophyll content (CCI Unit)
Lettuce					
Vertical NFT	5416.7c	9570.0c	5867.4c	2.86b	4.98b
Horizontal NFT	4931.0bc	9268.6bc	5003.2b	2.79a	4.25a
Non-Circulated	4336.0ab	9094.8b	4710.6b	2.78a	4.34ab
Soil System	3669.3a	8094.8a	3710.6a	2.72a	4.12a
Spinach					
Vertical NFT	12488.7b	9126.7c	3169.2b	5.67b	15.10b
Horizontal NFT	11699.1b	8264.1b	2971.6b	5.62b	15.07b
Non-Circulated	8994.1a	7367.0a	2723.9ab	5.16ab	14.30ab
Soil System	8040.4a	7055.3a	2186.2a	4.79a	13.22a

Data were shown in mean $\pm$ standard deviation (n = 12). Statistics show that the values in the same column with various letter values are significant by Duncan's test at $p \leq 0.05$

Anthocyanin and Chlorophyll in lettuce found ($P<0.05$) significantly highest in by vertical circulated system (2.86 ± 0.2 ACI and 4.98 ± 0.7 CCI) and lowest (2.72 ± 0.2 ACI and 4.12 ± 0.7 CCI) was recorded in soil system. Whereas, anthocyanin and Chlorophyll content in spinach significantly similar result show in vertical circulated, horizontal circulated but lowest was found in soil system. In lettuce and spinach crop significantly difference ($P<0.05$) was record in Anthocyanin and Chlorophyll content on hydroponic system and soil condition and high value content was recorded in spinach. Supporting current finding plant genetic variability and cultivar, specific location green house was affects the plant pigment contents of leafy vegetable cultivation. Caldwell and Britz (2006), Sapkota *et al.* 2019 and Öztekin *et al.* 2018. Anthocyanin and chlorophyll content some time affected by sunlight and day length in hydroponics system and soil cultivation to related leafy vegetable production Acharya *et al.* (2020). This thorough growth research proving that hydroponically produced lettuce is of worse grade than soil-grown vegetables. Lei and Engeseth (2021

4.1.3 Lettuce and spinach crop content of carbohydrates and total sweetness index: Glucose, fructose, sucrose and total sweetness index in lettuce and spinach were influenced by different hydroponic system and soil condition are depicted in table 3. The lettuce grows in vertical circulated exhibited highest glucose content (1172.8 ± 56.4), fructose content (1384.2 ± 27.5), sucrose content (92.3 ± 1.9) and total sweetness index ($3059.9\pm40.9d$), followed by horizontal circulated and non-circulated system, alongside lowest glucose content (761.4 ± 86.6), fructose content (908.8 ± 2.7), sucrose content (74.9 ± 3.9) and total sweetness index (2016.8 ± 69.2) in crops grown soil.

Whereas similar result in spinach grow in vertical circulated system glucose content ($2749.3\pm680.8b$), fructose content ($3187.3\pm42.9c$), sucrose content (160 ± 4.6) and total sweetness index (7030.5 ± 585.1) was ($p<0.05$) significantly highest values compared to soil grown crops glucose content (1649.5 ± 80.7), fructose (2694.8 ± 99.9), sucrose content (121.5 ± 8.7) and total sweetness index (5417.4 ± 143.7). From the results of lettuce, it was observed that glucose, fructose, sucrose and total sweetness index were found compared to lettuce. Supporting current finding Chen *et al* (2019). An increase in plant production necessitates a high atmospheric CO₂ fixation rate, sufficient nourishment, and water, which is accomplished by increasing sugar in plant body. Photosynthetic rate is a factor that regulates sugar concentration in vegetable tissues.

Table 4.3: Carbohydrates and total sweetness index in lettuce and spinach crops in hydroponic systems and soil control

Growing Conditions	Glucose (mg 100g⁻¹)	Fructose (mg 100g⁻¹)	Sucrose (mg 100g⁻¹)	Total Sweetness Index (TSI)
Lettuce				
Vertical NFT	1172.8c	1384.2d	92.3c	3059.9d
Horizontal NFT	1045.2bc	1235.0c	88.7bc	2735.6c
Non-Circulated	928.1b	1038.8b	86.2b	2349.8 b
Soil System	761.4a	908.8a	74.9a	2016.8a
Spinach				
Vertical NFT	2749.3b	3187.3c	160c	7030.5c
Horizontal NFT	2146.6ab	3024.1bc	151.9bc	6319.4b
Non-Circulated	1991.2a	2914.2b	148.1b	6032.7b
Soil System	1649.5a	2694.8a	121.5a	5417.4a

Data were shown in mean $\pm$ standard deviation (n = 12). Statistics show that the values in the same column with various letter values are significant by Duncan's test at $p \leq 0.05$

When compared to controls and other combinations, the bio fortified plants had higher levels of glucose, fructose, and total sugars Sularz et al (2020). According to studies, illumination modifications can enhance total soluble solids and soluble sugar concentrations while reducing NO₃ content. Guo et al (2019).

4.1.4 Lettuce and spinach crops content of mineral elements: The mineral Ca, Mg, B, Cu, Mn, Ni, Zn and Fe elements contents (mg 100g⁻¹) of the lettuce and spinach grow in different hydroponic and soil condition are given in Table 3. It was observed that the all mineral concentration result shows significant difference (P<0.05) in hydroponic systems compared to soil grow lettuce and spinach. In lettuce mineral like Ca, Mg, B, Ni and Zn was found significantly highest in vertical circulated system (Ca 80.47±9.95, Mg 65.74±10.19, B 0.51±0.10, Ni 0.07±0.01 and Zn 1.02±0.1 mg 100g⁻¹) compared other condition.

Cu and Fe concentration non- significant recorded (Range between Cu 0.12±0.01 to 0.13±0.01a and Fe 4.16±0.80 to 5.22±1.84 mg 100g⁻¹) in all growing condition and Mn concentration observed similar in vertical 1.06±0.12c mg 100g⁻¹) and horizontal (1.02±0.12 mg 100g⁻¹) circulated systems. The minerals lower value found in soil system (Ca 62.37±6.29, Mg 49.00±2.47, B 0.25±0.05, Cu 0.12±0.01, Fe 4.16±0.80, Mn 0.38±0.10, Ni 0.05±0.01 and Zn 0.57±0.19 mg 100g⁻¹).

It was observed in spinach B, Cu, Mn, Ni and Zn was found significantly maximum in vertical circulated system (B 0.52±0.08, Cu 0.19±0.5, Mn 1.48±0.37, Ni 0.05±0.01 and Zn 0.97±0.18 mg 100g⁻¹) compared other condition. The concentration of Ca, Mg and Fe significant similar recorded in vertical (Ca 84.41±7.43, Mg 101.36±9.05 and Fe 3.47±0.49 mg 100g⁻¹) and horizontal (Ca 78.50±5.14, Mg 97.04±11.99 and Fe 3.16±0.64 mg 100g⁻¹) circulated systems. The soil system minimum value minerals in (Ca 44.59±10.62, Mg 67.95±6.05, B 0.20±0.03a, Cu 0.09±0.29, Fe 1.49±0.33a Mn 0.50±0.27, Ni 0.02±0.01 and Zn 0.44±0.06 mg 100g⁻¹). The current finding mineral Ca, Mg, B, Cu, Mn, Ni, Zn and Fe elements contents (mg 100g⁻¹) of the lettuce and spinach higher in hydroponic systems and low in soil system. Supporting current finding Blasco (2011) and Frezza *et al.* (2005) advance the possibility of managing different cultural viz. nutrient supply, water supply and temperature by hydroponic technology to obtain high mineral nutritional quality and quantity products of vegetable crops comprehend to soil system. The effects of increasing growth solution compositions (macro and micro nutrients) on leafy vegetables are uneven in terms of production and quality, despite the fact that it is typically true that leafy vegetables are exposed to elevated light irradiance and temperature. As nutritional solution was applied, the concentrations of all the tested leaf elements rose. Sublett et al (2018).

Table 4.4: Mineral Ca, Mg, Zn, Fe, Cu, Mn, B and Ni elements contents (mg 100g⁻¹) in lettuce and spinach crops produces in hydroponic systems and soil control

Growing Conditions	Ca (mg 100g⁻¹)	Mg (mg 100g⁻¹)	Zn (mg 100g⁻¹)	Fe (mg 100g⁻¹)	Cu (mg 100g⁻¹)	Mn (mg 100g⁻¹)	B (mg 100g⁻¹)	Ni (mg 100g⁻¹)
Lettuce								
Vertical NFT	80.47b	65.74b	1.02c	5.22b	0.13a	1.06c	0.51c	0.07b
Horizontal NFT	68.30a	52.90a	0.83b	4.54a	0.13a	1.02c	0.41b	0.05a
Non-Circulated	62.94a	51.07a	0.70ab	5.04ab	0.12a	0.52b	0.38b	0.05a
Soil System	62.37a	49.00a	0.57a	4.16a	0.12a	0.38a	0.25a	0.05a
Spinach								
Vertical NFT	84.41c	101.36b	0.97c	3.47b	0.19b	1.48c	0.52c	0.05b
Horizontal NFT	78.50c	97.04b	0.81bc	3.16b	0.12ab	1.05b	0.42b	0.04ab
Non-Circulated	62.09b	91.02ab	0.73b	1.99a	0.12ab	0.88b	0.27a	0.03a
Soil System	44.59a	67.95a	0.44a	1.49a	0.09a	0.50a	0.20a	0.02a

Data were shown in mean $\pm$ standard deviation (n = 12). Statistics show that the values in the same column with various letter values are significant by Duncan's test at $p \leq 0.05$

4.2 Objective IIIrd. “To assess effects of seedling age and seasonal variations on yield and quality of spinach and lettuce in vertical circulated hydroponic system”. The experiment, lettuce (var. Grand rapid) and spinach (var. Delta) were grown NFT hydroponically under double layer polycarbonate greenhouse **condition during summer season of 2019.**

4.2.1 Plant growth and yield attributes of Spinach:

The study of Spinach grown under hydroponic NFT systems in different seeding ages and months on growth, morphology and yield attributing characters (plant height, number of leaf, leaf area, Root Length, Root Fresh Weight, Root Length, shoot fresh weight and yield) presented in Table 1 to 8. It was observed that the plant height of Spinach grown in greenhouse 25 DAS in month of July (28.0 ± 1.0 cm) was found maximum while followed by 30 DAS in month of August (26.3 ± 1.5 cm) and minimum plant height was found in April month 25 DAS (15.0 ± 1.0 cm).

Root length of Spinach grown in month of July 30 DAS exhibited maximum (25.2 ± 2 cm) followed by July 25 DAS month (24.3 ± 3.6 cm) and lowest value in April month 25 DAS (17.3 ± 2.1 cm) circulated system.

Leaf area of Spinach in 25 DAS in August month NFT system (99.8 ± 11.9 cm²) was significantly high ($P < 0.05$) than others and followed by 25 DAS in July month (99.6 ± 2.6 cm²). Minimum in 30 DAS April month (55.8 ± 3.3 cm²) grown crop. The root area of Spinach grown in July month 25 DAS (3479.6 ± 155.1 mm²) was higher than all treatments and followed by August 25 DAS (3416.7 ± 271.9 mm²) and lower in April month 25 DAS (2865.7 ± 327.7 mm²) grown crop. The maximum number of leaves per plant was recorded in 25 DAS in July month (22.9 ± 1) than August month 35 DAS (22.7 ± 3.1) and lowest number of leaves per plant was recorded in April month with 25 DAS (13 ± 2.6). Root fresh weight of Spinach grown in 30 DAS in month of August (20.3 ± 3.5 g) was found maximum while followed by 35 DAS in month of August (17.7 ± 3.4 g) and minimum root fresh weight was found in April month 25 DAS (6.3 ± 0.1 g). Spinach grown in NFT circulated system in 25 DAS in July month (59.2 ± 3.5 g and 3.67 ± 0.25 kg) exhibited maximum values for fresh weight gram per plant and yield kg m⁻² followed by July month with 30 DAS (57.8 ± 3.6 g and 3.57 ± 0.23 kg) and lowest value in 35 DAS in month April (31.4 ± 3.2 g and 1.97 ± 0.21 kg).

The plant growth parameter depending on uptake of nutrient and suitable climatic condition viz temperature and sun light is relation with plant nutritional quality. Growers must plant frequently and choose cultivars that perform well, are best-suited to certain growing conditions, have healthy, defect-free external appearances, and have internal or exposed seed stems since growth and yield production

change during the season. Studies are restricted to certain areas because of the interplay between genotype and environment that alter plant growth in response to particular climatic conditions. There are variations in temperature and/or light levels (such as day length, the quantity and quality of solar radiation, and a variety of other microclimatic factors). Research must be conducted close to possible commercial production areas for cultivar selection to be successful in any locality. Kobryn, (2001), (Wurr *et al.*, (1988); Al-Harbi, (2001), Sharma *et al.*, (2001), deVaus, (1976) and Kristensen *et al.*, 1987).

Table 4.5: Effects of seedling age and seasonal variations on plant height (cm) of spinach crop grown in vertical hydroponic systems

Sample Name	Plant Height (cm)						
	April	May	June	July	August	September	October
25DAS	15.0±1.0a	16.7±2.5a	25.7±0.6bc	28.0±1.0c	25.7±2.5bc	20.0±2.0ab	19.3±3.1ab
30DAS	17.7±1.5a	17.0±1.7a	22.0±2abc	23.7±4.7abc	26.3±1.5bc	18.3±2.5ab	18.7±4.0ab
35DAS	15.2±1.1a	17.7±2.1a	23.3±2.1abc	26.0±3bc	25.3±1.5bc	23±2.6abc	22.3±0.6abc

Data were shown in mean ± standard deviation (n = 63). The Statistics show that the values in the same column with various letter values are significant by Duncan's test at $p \leq 0.05$

Table 4.6: Effects of seedling age and seasonal variations on root length (cm) of spinach crop grown in vertical hydroponic systems

Sample Name	Root Length (cm)						
	April	May	June	July	August	September	October
25DAS	17.3±2.1a	22.3±2.1a	23.7±3.8a	24.3±3.6a	22.7±2.1a	21.7±2.1a	16.3±4.5a
30DAS	17.7±3.1a	20.3±2.5a	21±1.8a	25.2±2a	24.2±5.3a	23.7±3.5a	17.4±3.8a
35DAS	19.3±3.5a	20±2.6a	20±3a	23.7±5a	23.7±3.1a	21±2.6a	21±2a

Data were shown in mean ± standard deviation (n = 63). Statistics show that the values in the same column with various letter values are significant by Duncan's test at $p \leq 0.05$

Table 4.7: Effects of seedling age and seasonal variations on leaf area (cm²) of spinach crop grown in vertical hydroponic systems

Sample Name	Leaf Area (cm ²)						
	April	May	June	July	August	September	October
25DAS	63.4±5.4a	72.1±8.8ab	78.2±3.1abc	99.6±2.6c	99.8±11.9c	98.9±15.7c	66±5.7ab
30DAS	55.8±3.3a	67.4±2.8ab	77.6±11.2abc	96.7±11c	94.8±14.3bc	80.5±6.3abc	65.3±7.4ab
35DAS	57±1.7a	65.6±10.9ab	85.2±6bc	93.1±4.8bc	82.2±3.7abc	74.2±9abc	63.6±20.1

Data were shown in mean ± standard deviation (n = 63). Statistics show that the values in the same column with various letter values are significant by Duncan's test at $p \leq 0.05$.

Table 4.8: Effects of seedling age and seasonal variations on root area (mm²) of spinach crop grown in vertical hydroponic systems

Sample Name	Root Area (mm ²)						
	April	May	June	July	August	September	October
25DAS	2865.7±	3264.5±	3229±	3479.6±	3416.7±	3285.8±	3258.1±
	327.7a	440.1a	441.5a	155.1a	271.9a	276.2a	466.6a
30DAS	2984.7±	3012.7±	3132.4±	3130±	3255±	3104.4±	3178.6±
	413.7a	379.7a	312.2a	223.7a	559.3a	184.1a	163.9a
35DAS	3143.7±	3136.7±	3327.9±	3317.8±	3175.1±	3138.6±	3081.8±
	483.2a	607.3a	198.1a	565a	503.5a	335.1a	384.6a

Data were shown in mean ± standard deviation (n = 63). Statistics show that the values in the same column with various letter values are significant by Duncan's test at $p \leq 0.05$.

Table 4.9: Effects of seedling age and seasonal variations on leaf number plant⁻¹ of spinach crop grown in vertical hydroponic systems

Sample Name	Leaf number plant ⁻¹						
	April	May	June	July	August	September	October
25DAS	13.0±2.6a	14.7±2.1abc	19.0±1abcd	22.9±1d	21.0±2abcd	21.7±1.5dc	16.7±1.5abcd
30DAS	13.7±4.6ab	14.7±3.1abc	15.3±1.5abcd	16.7±3.2abcd	21.3±2.1cd	21.0±3abcd	16.0±1abcd
35DAS	14.7±1.5abc	16±2.6abcd	17.3±4abcd	17.3±1.5abcd	22.7±3.1d	19.7±2.1abcd	16.7±1.5abcd

Data were shown in mean ± standard deviation ($n = 63$). Statistics show that the values in the same column with various letter values are significant by Duncan's test at $p \leq 0.05$

Table 4.10: Effects of seedling age and seasonal variations on root fresh weight (g plant⁻¹) of spinach crop grown in vertical hydroponic systems.

Sample Name	Root Fresh Weight (g plant ⁻¹)						
	April	May	June	July	August	September	October
25DAS	6.3±1a	6.4±0.8a	12.2±1.8ab	13.6±0.9abc	16.3±1.2bc	13.4±5.5abc	10.3±1ab
30DAS	6.7±1.4a	7.4±2.4a	11.8±1ab	13.3±3.3abc	20.3±3.5bc	11.3±4.5ab	10.7±1.1ab
35DAS	7.2±1.4a	6.5±0.6a	12±2.3ab	12.2±3.3ab	17.7±3.4bc	17.1±3.9bc	11.3±2.1ab

Data were shown in mean ± standard deviation ($n = 63$). Statistics show that the values in the same column with various letter values are significant by Duncan's test at $p \leq 0.05$.

Table 4.11: Effects of seedling age and seasonal variations on Shoot Fresh Weight (g plant⁻¹) of spinach crop grown in vertical hydroponic systems.

Sample Name	Shoot Fresh Weight (g plant ⁻¹)						
	April	May	June	July	August	September	October
25DAS	31.6±3a	33.4±2.9abc	51.2±1.8de	59.2±3.5e	57.5±6.7e	51.5±3.9de	52.1±1de
30DAS	32±3.7ab	42±6.3abcd	46.9±3.5bcde	45.5±3.9bcde	57.8±3.6e	53.8±7.6de	46.5±4.1bcde
35DAS	31.4±3.2a	32.6±2.4abc	47.3±6.7cde	54.7±9.1de	53.4±5.3de	54.9±6.1de	50.8±3.4de

Data were shown in mean ± standard deviation ($n = 63$). Statistics show that the values in the same column with various letter values are significant by Duncan's test at $p \leq 0.05$

Table 4.12: Effects of seedling age and seasonal variations on yield (kg m⁻²) of spinach crop grown in vertical hydroponic systems

Sample Name	Yield (kg m ⁻²)						
	April	May	June	July	August	September	October
25DAS	1.98±0.15a	2.1±0.17ab	3.13±0.12cd	3.67±0.25d	3.56±0.42d	3.17±0.25cd	3.27±0.06cd
30DAS	2±0.26ab	2.57±0.4abc	2.9±0.26abcd	2.83±0.23abcd	3.57±0.23d	3.33±0.5cd	2.9±0.26abcd
35DAS	1.97±0.21a	2.03±0.15ab	2.93±0.42bcd	3.37±0.55cd	3.33±0.32cd	3.37±0.38cd	3.13±0.21cd

Data were shown in mean ± standard deviation ($n = 63$). Statistics show that the values in the same column with various letter values are significant by Duncan's test at $p \leq 0.05$.

4.2.2 Sugar profiling and pigment contents of Spinach

Plant Sugar profiling and total sweetness index of Spinach as influenced by different growing seedling age and months in hydroponic system are described in Fig 4.1 to 4.4. In Spinach, highest glucose ($2351.5 \text{ mg } 100\text{g}^{-1}$) in July month 25 DAS and fructose ($3196 \text{ mg } 100\text{g}^{-1}$), sucrose ($168.7 \text{ mg } 100\text{g}^{-1}$) and TSI (6690.3) content was observed in 35 DAS in month of August followed by fructose ($3189.6 \text{ mg } 100\text{g}^{-1}$, sucrose ($162.3 \text{ mg } 100\text{g}^{-1}$) and TSI (6596.9) contain in 35 DAS July month and glucose in June month 25 DAS ($2289.2 \text{ mg } 100\text{g}^{-1}$). Whereas, lowest glucose ($1968.6 \text{ mg } 100\text{g}^{-1}$) and TSI (5973.936), content was recorded in April month 30 DAS and fructose ($2875.2 \text{ mg } 100\text{g}^{-1}$) and sucrose ($139.8 \text{ mg } 100\text{g}^{-1}$) content was recorded in April month 25 DAS.

Plant leaf pigment anthocyanin and chlorophyll contents of Spinach as influenced by various Seedling age and months under hydroponic system described in table... The August month 30 DAS anthocyanin content ($6.33 \pm 0.15 \text{ ACI}$) and July month 25 DAS chlorophyll content ($19.4 \pm 1.1 \text{ CCI}$) under circulated system exhibited significantly highest followed by July month 25 DAS anthocyanin content ($6.2 \pm 2.34 \text{ ACI}$) and July month 30 DAS chlorophyll content ($18.4 \pm 3.4 \text{ CCI}$) with NFT system. The Spinach in April month 25 DAS anthocyanin content ($3.2 \pm 0.36 \text{ ACI}$) and chlorophyll content ($14 \pm 1.4 \text{ CCI}$) showed lowest. Plant production quality depends on the climate for plants to flourish in a hydroponic system with enough nutrients supplied. While sugar profiles and pigment concentrations were altered during the plant's greatest growth, increasing weather conditions had an impact on growth features during early growth. Due primarily to the higher temperatures and light levels (Day Lighting time), these growth parameters showed significant seasonal and varietal changes with higher growth rates with sugar profile and pigment contents observed inspiring than those in July and August. (Radovich *et al.*, 2004; Acharya *et al.* 2021),

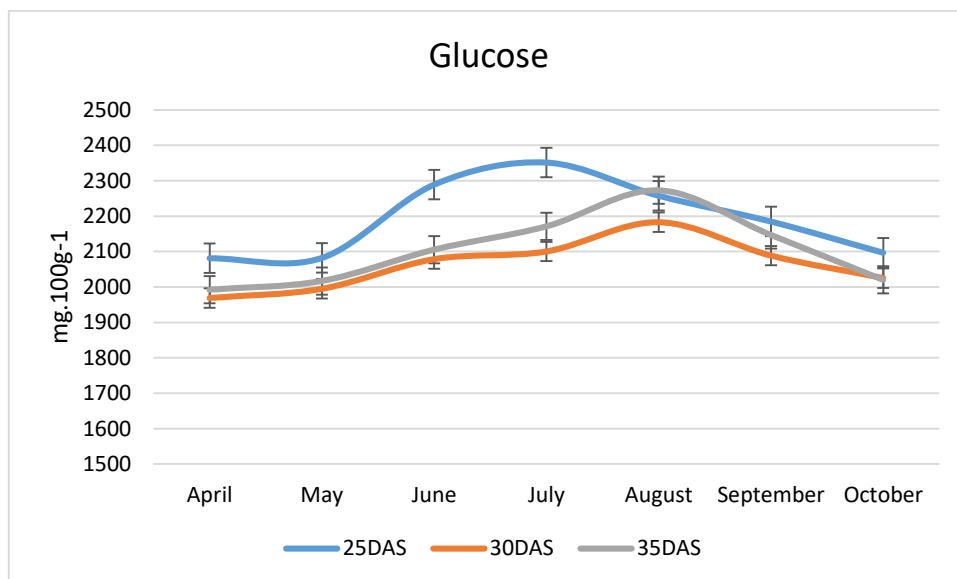


Fig. 4.1 Effects of seedling age and seasonal variations on glucose content in spinach crop grown in vertical hydroponic systems

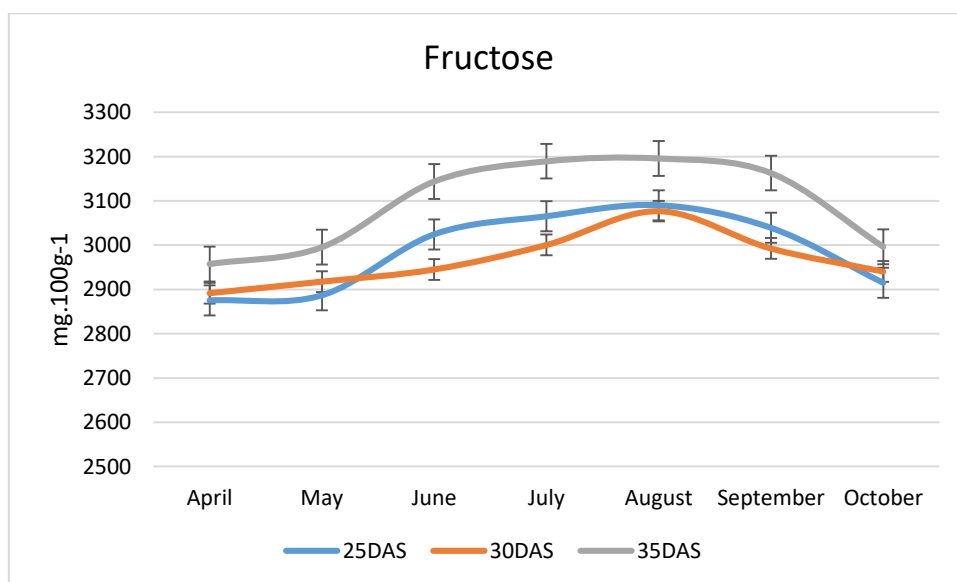


Fig. 4.2 Effects of seedling age and seasonal variations on fructose content in spinach crop grown in vertical hydroponic systems

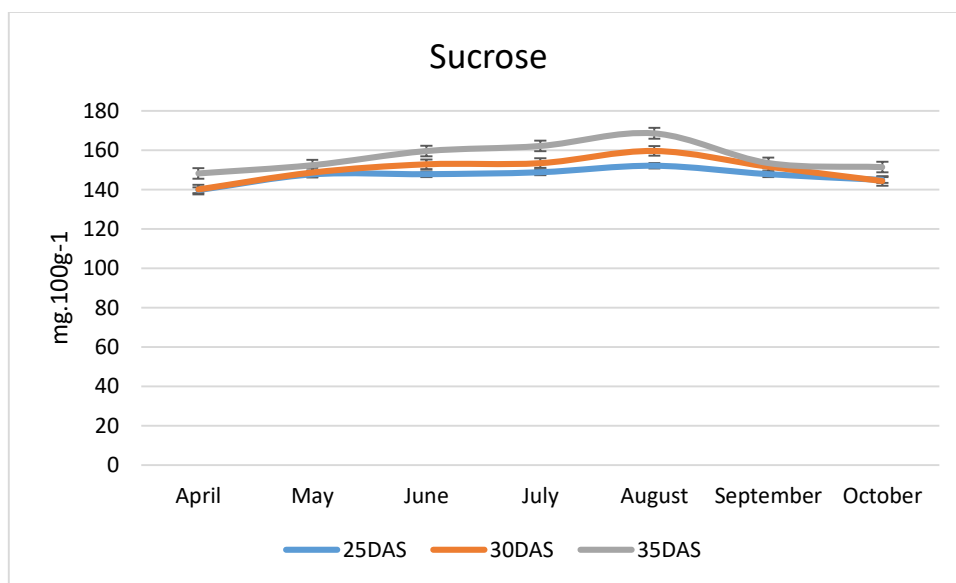


Fig. 4.3 Effects of seedling age and seasonal variations on sucrose content in spinach crop grown in vertical hydroponic systems

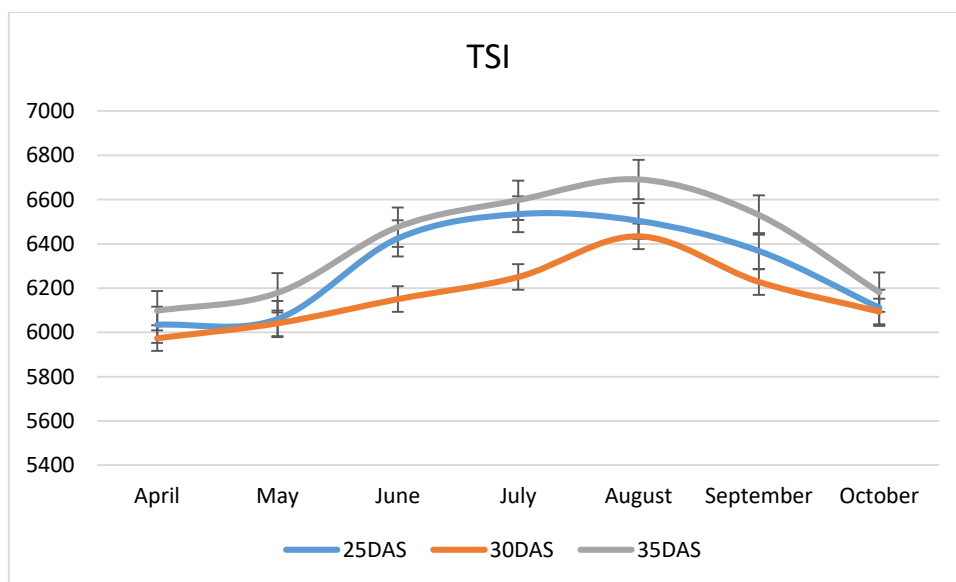


Fig. 4.4 Effects of seedling age and seasonal variations on TSI content in spinach crop grown in vertical hydroponic systems.

Table 4.13: Effects of seedling age and seasonal variations on anthocyanin content (ACI Unit) of spinach crop grown in vertical hydroponic systems

Sample Name	Anthocyanin Content (ACI Unit)						
	April	May	June	July	August	September	October
25DAS	3.2±0.36a	3.97±0.21a	5.77±1.42a	6.2±2.34a	5.81±0.35a	5.89±0.65a	4.47±1.02a
30DAS	3.63±0.5a	4.17±0.21a	4.87±1.27a	5.1±0.89a	6.33±0.15a	5.13±0.06a	4.73±0.49a
35DAS	4.17±0.87a	5.3±1.08a	5.87±0.49a	5.93±1.88a	6.07±0.78a	5.47±0.67a	5.07±2.06a

Data were shown in mean ± standard deviation ($n = 63$). Statistics show that the values in the same column with various letter values are significant by Duncan's test at $p \leq 0.05$

Table 4.14: Effects of seedling age and seasonal variations on chlorophyll content (CCI Unit) of spinach crop grown in vertical hydroponic systems

Sample Name	Chlorophyll Content (CCI Unit)						
	April	May	June	July	August	September	October
25DAS	14±1.4a	14.6±1.5a	15.9±0.5a	19.4±1a	17.5±0.7a	16.2±0.9a	14.7±0.3a
30DAS	14.1±2.2a	15.3±2.6a	17±0.7a	18.4±3.4a	16.5±0.9a	16.4±1.5a	13.4±1.4a
35DAS	14.2±2.9a	16.8±1.5a	16.9±0.3a	17.6±5a	16.1±0.8a	15.7±1.6a	15.2±3a

Data were shown in mean ± standard deviation ($n = 63$). Statistics show that the values in the same column with various letter values are significant by Duncan's test at $p \leq 0.05$.

4.2.3 Macro and Micro nutrients of Spinach

Spinach grown in different seedling age and month growing on plant quality parameters viz. nitrate, phosphate, sulphate calcium and magnesium content of leaves (Fig 4.5 to 4.12). Plant nutrient was significantly affected by the growth and production of plant system. While analysing the quality attributes of leafy Spinach 30 DAS in June month nitrate ($1227.8 \text{ mg kg}^{-1}$), 35 DAS in August month phosphate (914.8 mg kg^{-1}) and 35 DAS in June month sulphate (334.3 mg kg^{-1}), and magnesium (98.3 mg kg^{-1}) 35 DAS in June month exhibited the maximum content followed by 25 DAS in July month nitrate ($1224.9 \text{ mg kg}^{-1}$), 35 DAS in July month phosphate (913.2 mg kg^{-1}) and 25 DAS in August month sulphate (333.5 mg kg^{-1}) and magnesium (98.2 mg kg^{-1}) 35 DAS in may month. The Minimum nitrate (900.3 mg kg^{-1}) 25 and phosphate (737.6 mg kg^{-1}) 30 DAS in April month and sulphate (256 mg kg^{-1}) and magnesium (95.5 mg kg^{-1}) 25 DAS in April month (Ayaz and Yurttagül 2006).

Spinach crops growing different conditions Cu, Mn, Zn and Fe mineral concentration ($\text{mg } 100\text{g}^{-1}$ fresh weight) of are shown in Fig 3. Spinach grown in different growing seedling age and months under hydroponic systems showed non-significant effects ($P < 0.05$) on plant quality parameters viz. Cu, Mn, Zn and Fe content. Micronutrient content was significantly affected by the reproduction system of plant. While analysing the quality attributes of leafy Spinach under hydroponic system exhibited the maximum mineral content Cu (0.14 mg kg^{-1}) And Zn (1.29 mg kg^{-1}) 25 DAS in August month, Mn (1.11 mg kg^{-1}) 25 DAS in July month, and Fe (5.29 mg kg^{-1}) 30 DAS in August month followed by Mn (1.10 mg kg^{-1}) 30 DAS in August month, Zn (1.27 mg kg^{-1}) 35 DAS in July month, Fe (5.05 mg kg^{-1}) 25 DAS in August month and Cu (0.13 mg kg^{-1}) in 30 DAS June and July and 35 DAS August month, while minimum content was recorded in plants in Cu (0.07 mg kg^{-1}), Mn (0.86 mg kg^{-1}) and Fe (3.62 mg kg^{-1}) 30 DAS in April month, and Zn (0.48 mg kg^{-1}) 35 DAS in April month. The plant nutrient uptake increasing to increase nutritional quality of crop produces yield in favourable condition. Given the lack of reaction seen during early growth, it would be viable to implement a ramping nutrient solution program, with a climate condition that raises Macro and Micro nutrients by rapid growth to a maximum concentration. However, a deeper comprehension of such mineral nutrient management with the assessment of the ideal growing conditions. (Di Gioia *et al.* 2017, Benincasa *et al.*, 2011, Tei *et al.*, 2003, Romheld 2012 and Hartz *et al.*, 2007)

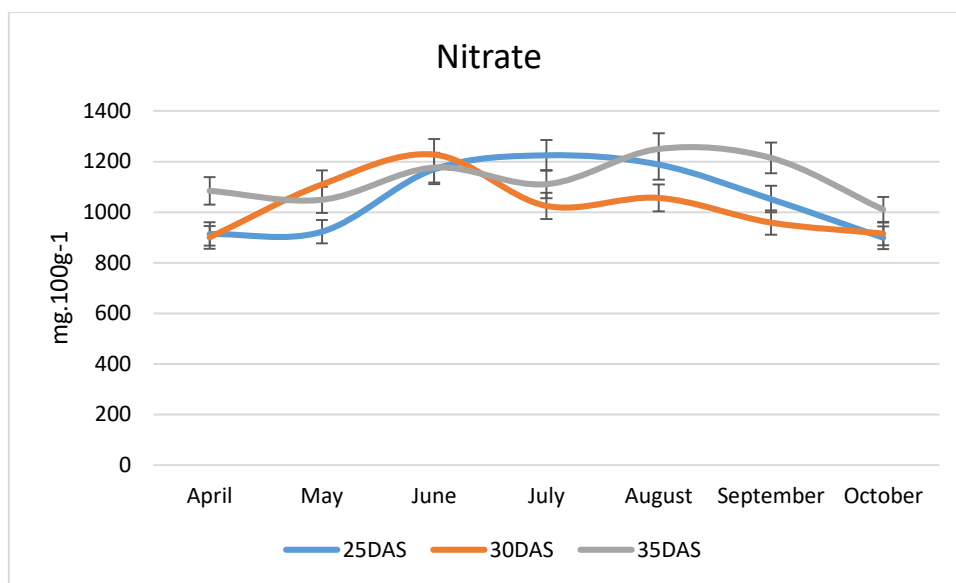


Fig. 4.5 Effects of seedling age and seasonal variations on nitrate content in spinach crop grown in vertical hydroponic systems

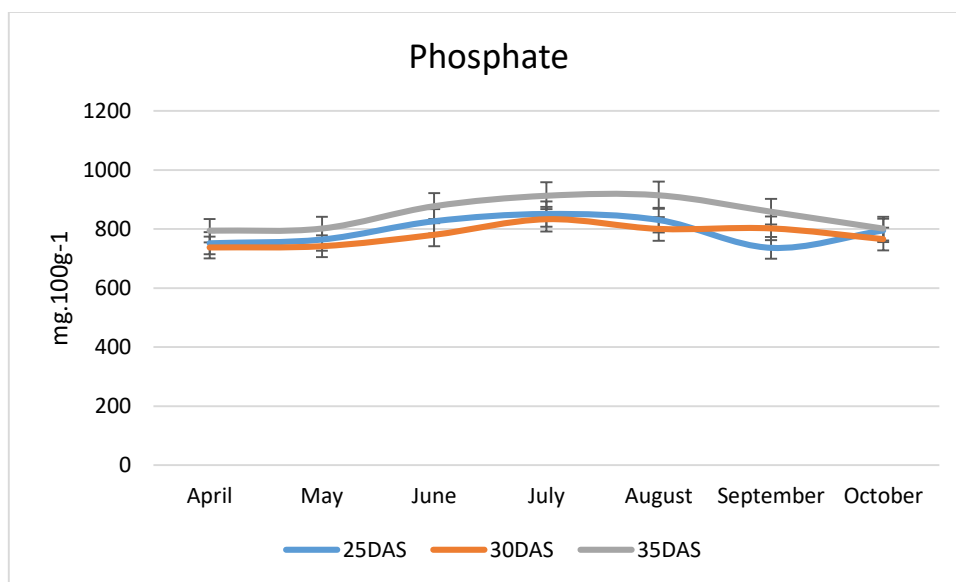


Fig. 4.6 Effects of seedling age and seasonal variations on phosphate content in spinach crop grown in vertical hydroponic systems

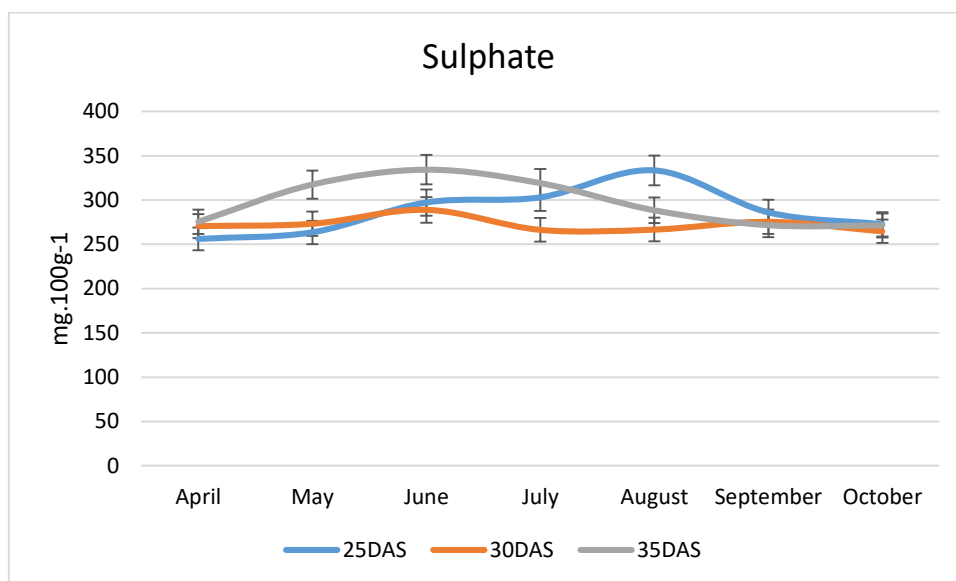


Fig. 4.7 Effects of seedling age and seasonal variations on sulphate content in spinach crop grown in vertical hydroponic systems

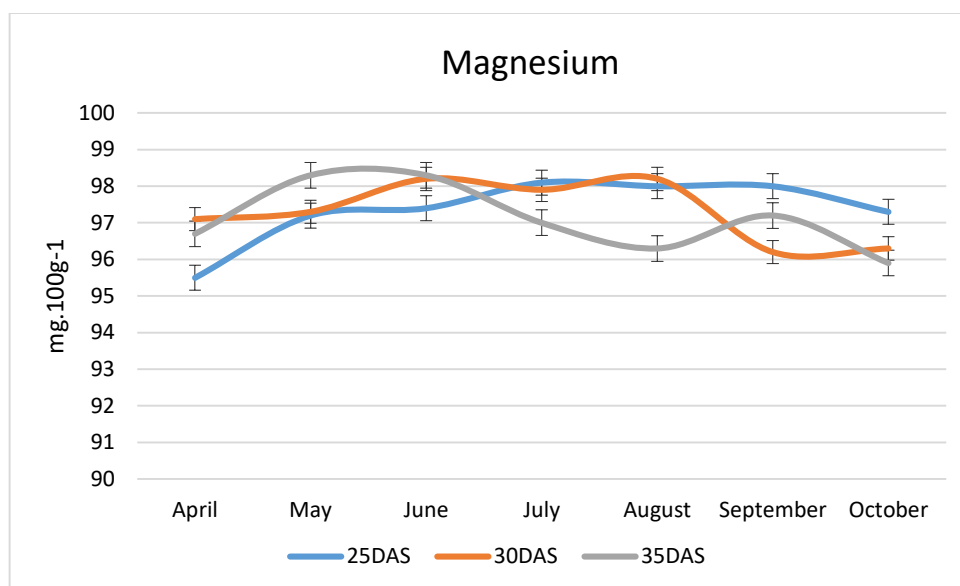


Fig. 4.8 Effects of seedling age and seasonal variations on magnesium content in spinach crop grown in vertical hydroponic systems

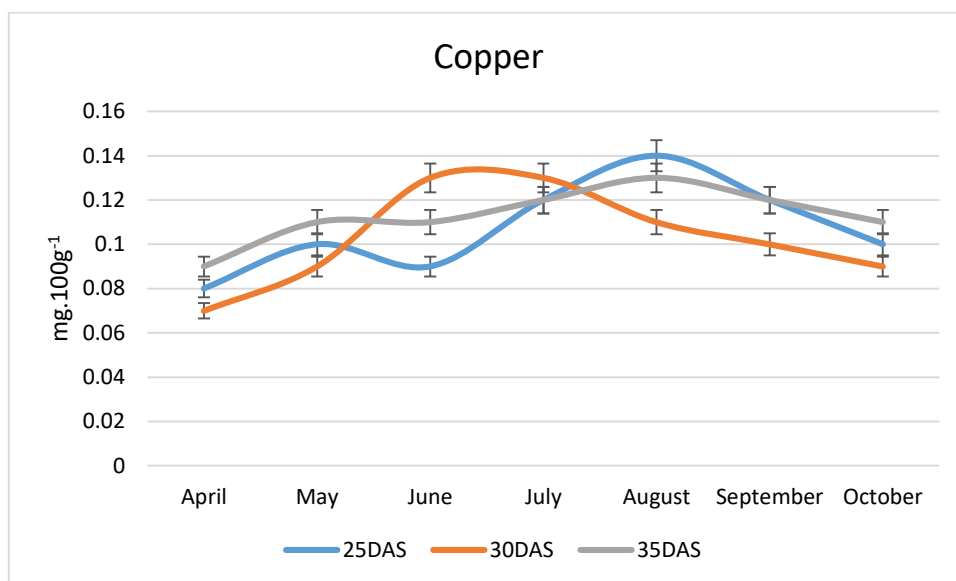


Fig. 4.9 Effects of seedling age and seasonal variations on copper content in spinach crop grown in vertical hydroponic systems

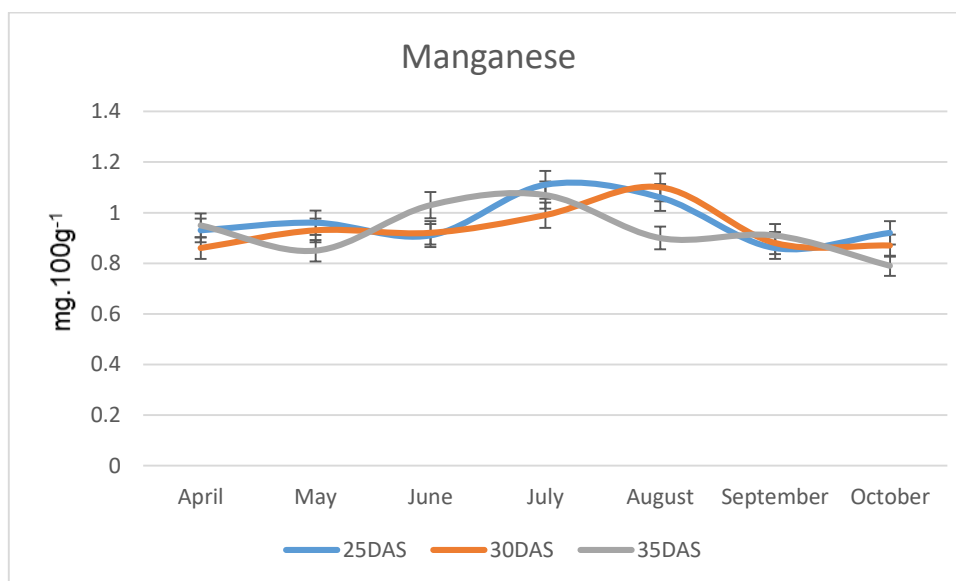


Fig. 4.10 Effects of seedling age and seasonal variations on manganese content in spinach crop grown in vertical hydroponic systems

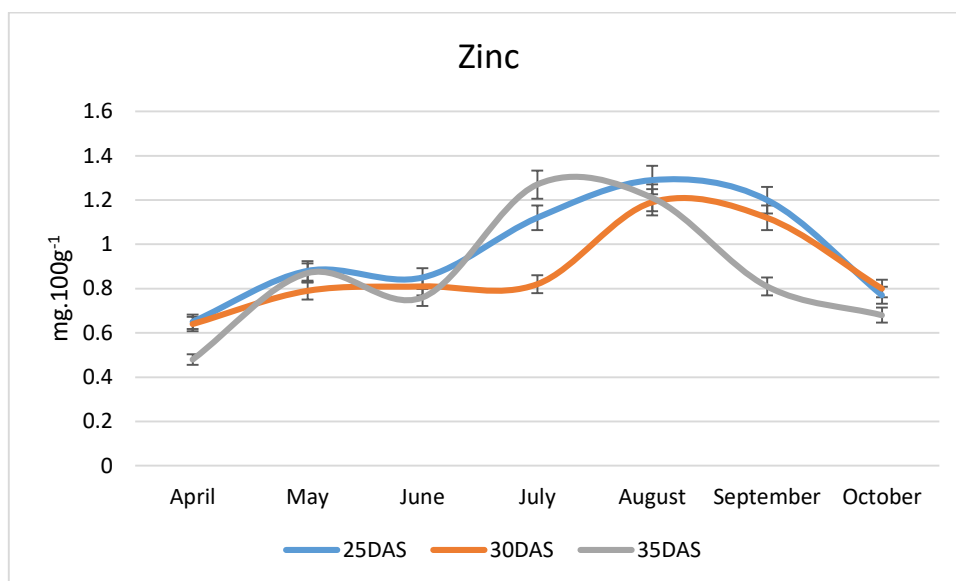


Fig. 4.11 Effects of seedling age and seasonal variations on zinc content in spinach crop grown in vertical hydroponic systems

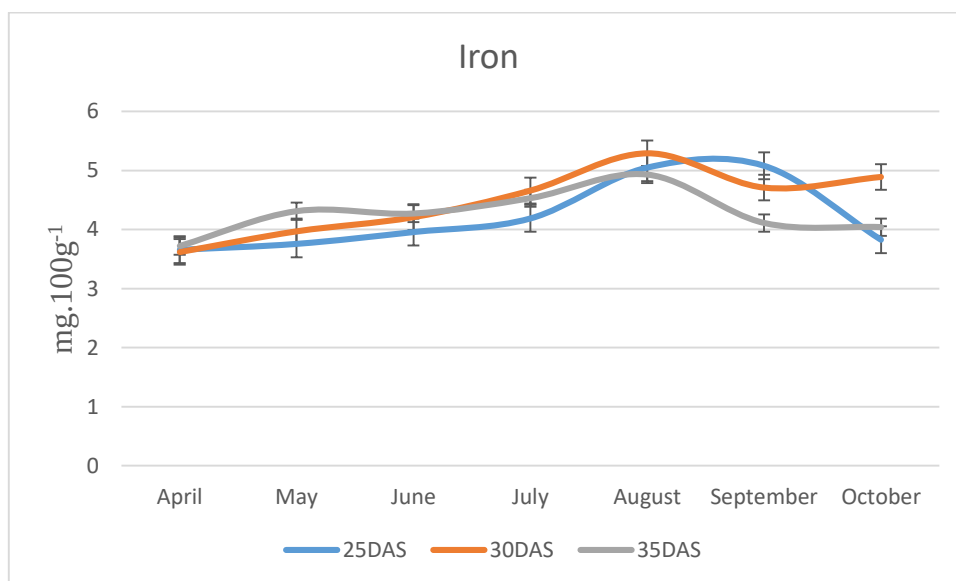


Fig. 4.12 Effects of seedling age and seasonal variations on iron content in spinach crop grown in vertical hydroponic systems

Crop: Lettuce

4.2.4 Plant growth and yield attributes of Lettuce:

The study of Lettuce grown under hydroponic NFT systems in different seeding ages and months on growth, morphology and yield attributing characters (plant height, Root Length, number of leaf, leaf area, Root Length, Root Fresh Weight, shoot fresh weight and yield) presented in Table 1 to 8. It was observed that the plant height of lettuce grown in greenhouse 30 DAS in month of July (23.3 ± 2.6 cm) was found maximum while followed by 25 DAS in month of June (23 ± 2.6 cm) minimum plant height was found in April month 35 DAS (17.1 cm). Root length of lettuce grown in month of June 30 DAS exhibited maximum (18.8 ± 1 cm) followed by July 35 DAS month (18.7 ± 1.5 cm) and lowest value in April month 35 DAS (12.7 ± 2.5 cm) circulated system. Leaf area of Lettuce in 30 DAS in July month NFT system (96.7 ± 2 cm²) was significantly high ($P < 0.05$) than others and followed by 25 DAS in August month (90.1 ± 3.5 cm²). Minimum in 35 DAS April month (60.9 ± 5.1 cm²) grown crop. The root area of lettuce grown in July month 25 DAS (3591 ± 647.5 mm²) was higher than all treatments and followed by July 30 DAS (3491.4 ± 148.3 mm²) and lower in October month 35 DAS (2422.8 ± 399 mm²) grown crop. The higher number of leaves per plant was recorded in 30 DAS in July month (12.4 ± 2.5) than August month 35 DAS (12.3 ± 1.5) and lower number of leaves per plant was observed in October month with 35 DAS (8.67 ± 1.53). Root weight of lettuce grown in 35 DAS in month of July (15.1 ± 3.2 g) was found maximum while followed by 25 DAS in month of July (14.3 ± 1.2 g) minimum plant height was found in April month 25 DAS (6.3 ± 0.3 g). Lettuce grown in NFT circulated system in 30 DAS in July month (67.1 ± 1.2 g and 4.17 ± 0.06 kg) exhibited maximum values for fresh weight gram per plant and yield kg m⁻² followed by July month with 25 DAS (60.6 ± 4.1 g and 3.73 ± 0.23 kg) and lowest value in 35 DAS in month April (37.9 ± 2.2 g and 2.36 ± 0.15 kg). According to a thorough analysis of the data used to estimate lettuce maturity using heat unit summations, lettuce yields often increased when cultivated in warmer climates as opposed to colder ones. Growth, development, and maturation are hastened in warmer regions where more heat units accumulate more quickly. Marketable yields were significantly higher than in the milder months of April, May, June, September, and October during the months with the highest average temperatures, which were July and August. (Jovicich *et al.* 2003, Lenzi *et al.* 2011 and Kara, 1993)

Table 4.15: Effects of seedling age and seasonal variations on plant height (cm) of lettuce crop grown in vertical hydroponic systems

Sample Name	Plant Height (cm)						
	April	May	June	July	August	September	October
25DAS	18.7±3.2a	20.5±3.2a	23±2.6a	22.7±1.5a	18.9±2.1a	18±1a	17.1±1a
30DAS	19±3.6a	20.3±3.2a	21.7±2.1a	23.3±2a	19.1±3a	18.3±1.5a	18.1±3a
35DAS	17±1a	18.5±2.1a	18.8±1.2a	19.7±2.1a	19±2a	18.4±0.4a	17.3±0.6a

Data were shown in mean ± standard deviation (n = 63). Statistics show that the values in the same column with various letter values are significant by Duncan's test at $p \leq 0.05$.

Table 4.16: Effects of seedling age and seasonal variations on Root Length (cm) of lettuce crop grown in vertical hydroponic systems

Sample Name	Root Length (cm)						
	April	May	June	July	August	September	October
25DAS	14±2a	15.5±3.2a	16.3±1.5a	18.5±2.1a	17.5±2.5a	17±3a	16.7±2.1a
30DAS	14.7±2.3a	16±2.6a	18.8±1a	17.1±2.5a	15.3±3.2a	14.5±3.1a	14.3±3.2a
35DAS	12.7±2.5a	15.8±2a	18.1±2.1a	18.7±1.5a	15.1±4.2a	14.7±2.9a	13.7±2.9a

Data were shown in mean ± standard deviation (n = 63). Statistics show that the values in the same column with various letter values are significant by Duncan's test at $p \leq 0.05$.

Table 4.17: Effects of seedling age and seasonal variations on Leaf Area (cm²) of lettuce crop grown in vertical hydroponic systems.

Sample Name	Leaf Area (cm ²)						
	April	May	June	July	August	September	October
25DAS	64.1±6.8a	81.5±4.9abc	78.7±8.4abc	84.1±6.4abc	90.1±3.5bc	78.7±8.4abc	81.4±3.7abc
30DAS	63.5±4.2a	74.7±4.7abc	77.8±3.7abc	96.7±2c	89.5±6bc	70.2±3.2ab	70.5±6ab
35DAS	60.9±5.1a	71.1±6.5ab	73.3±7.9abc	85.2±4.5abc	70.4±4.4ab	69.1±9.4ab	64.5±8.1a

Data were shown in mean ± standard deviation (n = 63). Statistics show that the values in the same column with various letter values are significant by Duncan's test at $p \leq 0.05$.

Table 4.18: Effects of seedling age and seasonal variations on Root Area (mm²) of lettuce crop grown in vertical hydroponic systems

Sample Name	Root Area (mm ²)						
	April	May	June	July	August	September	October
25DAS	2992.8±309.9a	3056.7±408.4a	3421±647.5a	3591±647.5a	3414.4±670.3a	3131.9±148.8a	2909.2±230.4a
30DAS	2823.2±254.2a	2955.4±410.8a	3228.5±210.9a	3491.4±148.3a	3319.4±305.5a	3164.7±561.4a	2759.3±216.9a
35DAS	2994±431.4a	3008±462.8a	3039.4±696.7a	3214.5±590.8a	3228.9±251a	2749±340.7a	2422.8±399a

Data were shown in mean ± standard deviation (n = 63). Statistics show that the values in the same column with various letter values are significant by Duncan's test at $p \leq 0.05$.

Table 4.19: Effects of seedling age and seasonal variations on Leaf Number plant⁻¹ of lettuce crop grown in vertical hydroponic systems

Sample Name	Leaf Number plant ⁻¹						
	April	May	June	July	August	September	October
25DAS	8.7±1.5a	9.7±1.5a	10.7±3.8a	11±2a	11±1a	10.7±0.6a	10.3±1.5a
30DAS	9.3±1.2a	9.9±0.6a	11.7±1.5a	12.4±2.5a	12±1a	11.7±2.1a	10.3±2.1a
35DAS	9±2.6a	9.6±1.5a	9.7±1.2a	11±1a	12.3±1.5a	10±1a	8.67±1.53a

Data were shown in mean ± standard deviation (n = 63). Statistics show that the values in the same column with various letter values are significant by Duncan's test at $p \leq 0.05$.

Table 4.20: effects of seedling age and seasonal variations on root fresh weight (g plant⁻¹) of lettuce crop grown in vertical hydroponic systems

Sample Name	Root Fresh Weight (g plant ⁻¹)						
	April	May	June	July	August	September	October
25DAS	6.3±0.3a	7.7±0.5ab	8.2±0.3abc	14.3±1.2bc	13.2±2.4abc	12.3±1abc	9.3±2.6abc
30DAS	6.7±1.3a	7.4±1.4ab	8.5±1.4abc	11.7±3.5abc	10.7±1.6abc	9.8±2.5abc	9.4±0.8abc
35DAS	7.1±1a	7.5±0.6ab	8.3±1abc	15.1±3.2c	12.2±2.4abc	9.9±2.1abc	8.5±1abc

Data were shown in mean ± standard deviation (n = 63). Statistics show that the values in the same column with various letter values are significant by Duncan's test at $p \leq 0.05$.

Table 4.21: effects of seedling age and seasonal variations on shoot fresh weight (g plant⁻¹) of lettuce crop grown in vertical hydroponic systems

Sample Name	Shoot Fresh Weight (g plant ⁻¹)						
	April	May	June	July	August	September	October
25DAS	43.1±5.1a	45.1±1.9a	48.7±4.7ab	60.6±4.1bc	46±3.7ab	38.8±1.8a	41.8±3.9a
30DAS	40.2±0.7a	42.4±3.4a	46.4±4.3ab	67.1±1.2c	47.8±7.3ab	40.3±2.2a	38±3.4a
35DAS	37.9±2.2a	44.3±6a	45.1±2.5a	52.5±4.6abc	48.1±7.8ab	41.5±3.1a	42.7±2.2a

Data were shown in mean ± standard deviation (n = 63). Statistics show that the values in the same column with various letter values are significant by Duncan's test at $p \leq 0.05$.

Table 4.22: Effects of seedling age and seasonal variations on Yield (kg m⁻²) of lettuce crop grown in vertical hydroponic systems

Sample Name	Yield (kg m ⁻²)						
	April	May	June	July	August	September	October
25DAS	2.63±0.32a	2.8±0.1a	3±0.26ab	3.73±0.23bc	2.83±0.38ab	2.4±0.1a	2.57±0.38a
30DAS	2.5±0.25a	2.67±0.21a	2.87±0.38ab	4.17±0.06c	2.97±0.57ab	2.5±0.1a	2.37±0.35a
35DAS	2.36±0.15a	2.73±0.4a	2.8±0.17a	3.23±0.45ab	3±0.46ab	2.57±0.15a	2.63±0.12a

Data were shown in mean ± standard deviation (n = 63). Statistics show that the values in the same column with various letter values are significant by Duncan's test at $p \leq 0.05$.

4.2.5 Sugar profiling and pigment contents of Lettuce

Plant Sugar profiling and total sweetness index of Lettuce as influenced by different growing seedling age and months in NFT hydroponic system are described in Fig. 4.13 to 4.16. In Lettuce, highest glucose ($1071.6\text{mg } 100\text{g}^{-1}$), fructose ($1293.7\text{mg } 100\text{g}^{-1}$), sucrose ($97.1\text{mg } 100\text{g}^{-1}$) and TSI (2852.1) content was observed in 30 DAS in month of August followed by fructose ($1238\text{mg } 100\text{g}^{-1}$, sucrose ($95.7\text{ mg } 100\text{g}^{-1}$) and TSI (2749.3) contain in 35 DAS August month and glucose in July month 30 DAS ($1053.2\text{ mg } 100\text{g}^{-1}$). Whereas, lowest glucose ($902.1\text{mg } 100\text{g}^{-1}$), fructose ($997.5\text{ mg } 100\text{g}^{-1}$), sucrose ($77.1\text{ mg } 100\text{g}^{-1}$) and TSI (2258.9), content was recorded in April month 25 DAS (Cocetta *et al.* 2007).

Plant leaf pigment anthocyanin and chlorophyll contents of Lettuce as influenced by various Seedling age and months under hydroponic system described in table. The July month 25 DAS and anthocyanin content ($2.77\pm0.29\text{ ACI}$) and July month 30 DAS chlorophyll content ($5.9\pm0.36\text{ CCI}$) under circulated system exhibited significantly highest followed by June month 30 DAS anthocyanin content ($2.71\pm0.21\text{ ACI}$) and June month 25 DAS chlorophyll content ($5.77\pm0.4\text{ CCI}$) with NFT system. The Lettuce in October month 25 DAS anthocyanin content ($1.7\pm0.2\text{ ACI}$) and October month 30 DAS chlorophyll content (3.13 ± 0.85) showed lowest. Factory product quality is depending on climatic condition for factory growing with sufficient nutrient force in hydroponic system. When a factory was growing stylishly, adding rainy conditions had a positive impact on sugar profiling and color contents but had a negative impact on growth features during early growth. Because of the advanced temperature and light conditions (daylight hours), these growth attributes showed fewer seasonal and varietal differences with advanced growth rates and color contents than those in July and August. (Singer *et al.* 2001 Somen *et al.* 2021 and Agarwal *et al.* 2021).

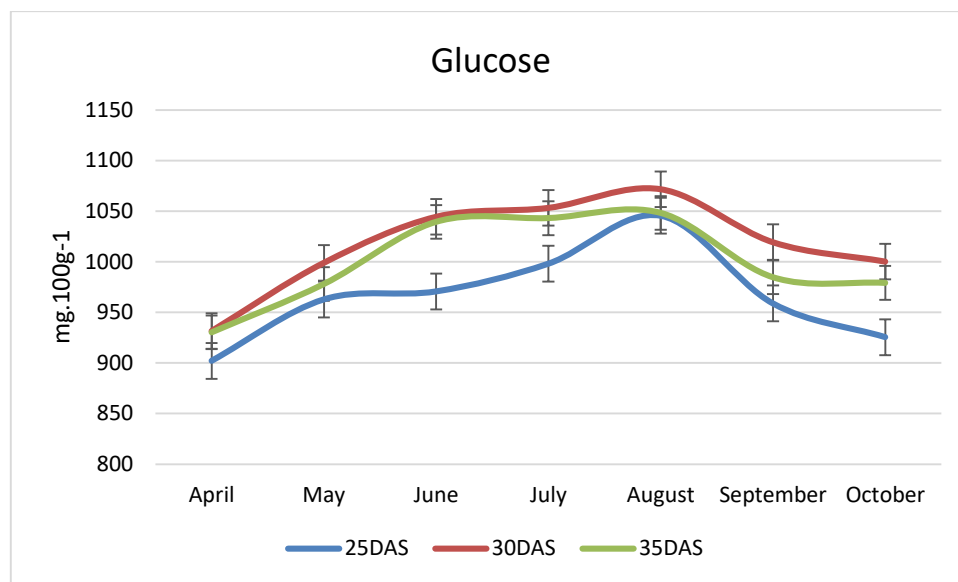


Fig. 4.13 Effects of seedling age and seasonal variations on glucose content in lettuce crop grown in vertical hydroponic systems

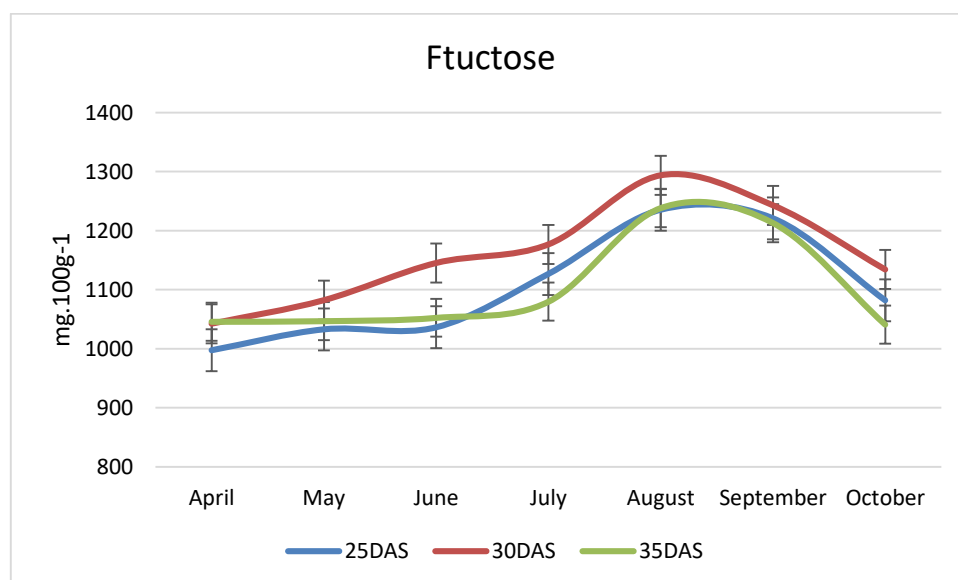


Fig. 4.14 Effects of seedling age and seasonal variations on fructose content in lettuce crop grown in vertical hydroponic systems

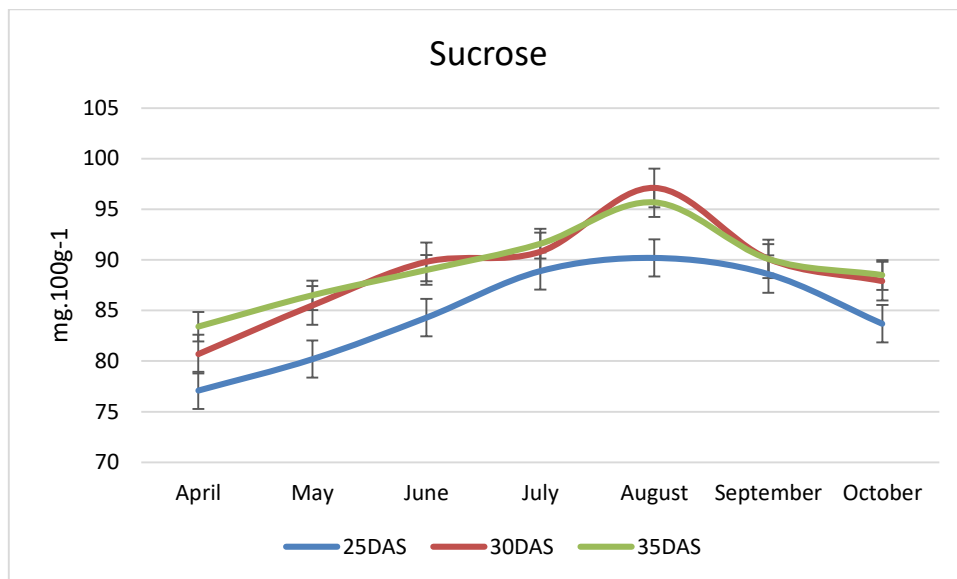


Fig. 4.15 Effects of seedling age and seasonal variations on sucrose content in lettuce crop grown in vertical hydroponic systems

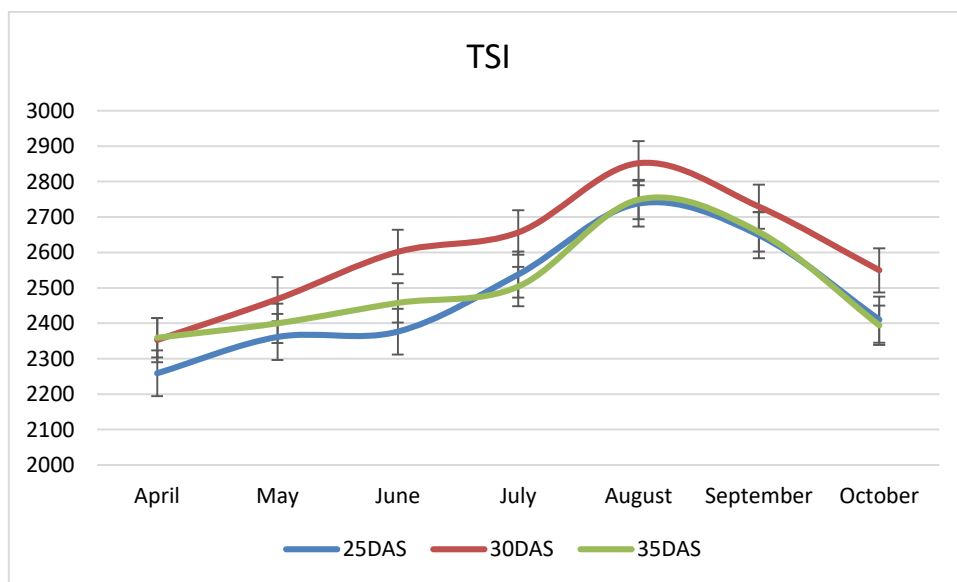


Fig. 4.16 Effects of seedling age and seasonal variations on TSI content in lettuce crop grown in vertical hydroponic systems.

Table 4.23: Effects of seedling age and seasonal variations on anthocynin content (ACI Unit) content in Lettuce crop grown in vertical hydroponic systems

Sample Name	Anthocynin Content (ACI Unit)						
	April	May	June	July	August	September	October
25DAS	2.23±0.21ab	2.1±0.1ab	2.2±0.17ab	2.77±0.29b	2.07±0.21ab	2.13±0.21ab	1.7±0.2a
30DAS	2.27±0.35ab	2.6±0.56ab	2.71±0.21b	1.83±0.12a	2.27±0.25ab	1.8±0.17a	1.77±0.29a
35DAS	2.03±0.15ab	2.6±0.44ab	2.43±0.15ab	2.77±0.59b	2.53±0.25ab	2.43±0.5ab	1.97±0.12ab

Data were shown in mean ± standard deviation (n = 63). Statistics show that the values in the same column with various letter values are significant by Duncan's test at $p \leq 0.05$.

Table 4.24: Effects of seedling age and seasonal variations on chlorophyll content (CCI Unit) content in lettuce crop grown in vertical hydroponic systems

Sample Name	Chlorophyll Content (CCI Unit)						
	April	May	June	July	August	September	October
25DAS	4.3±0.46abc	5.77±0.42c	5.77±0.4c	4.67±0.25abc	3.7±0.2abc	2.93±0.45a	3.43±0.68ab
30DAS	4.67±0.5abc	5.3±0.72bc	4.63±0.4abc	5.9±0.36c	3.3±0.26ab	3.4±0.6ab	3.13±0.85ab
35DAS	3.5±0.17ab	5.13±0.68abc	5.1±0.75abc	4.67±1.68abc	3.47±0.21ab	3.37±1.33ab	3.27±1.25ab

Data were shown in mean ± standard deviation (n = 63). Statistics show that the values in the same column with various letter values are significant by Duncan's test at $p \leq 0.05$.

4.2.6 Macro and Micro nutrients of Lettuce;

Lettuce grown in different seedling age and month growing on plant quality parameters viz. nitrate, phosphate, sulphate calcium and magnesium content of leaves (Fig). Plant nutrient was significantly impact by the growth and production of plant system. While analysing the quality attributes of leafy Lettuce 25 DAS in July month nitrate (507.7 mg kg^{-1}), 25 DAS in August month phosphate (946.5 mg kg^{-1}) and 25 DAS in July month sulphate (566.2 mg kg^{-1}), and magnesium (70.6 mg kg^{-1}) 25 DAS in august month exhibited the maximum content followed by 25 DAS in august month nitrate (490.3 mg kg^{-1}), 35 DAS in July month phosphate (943.3 mg kg^{-1}) and 35 DAS in July month sulphate (531.6 mg kg^{-1}) and magnesium (70.1 mg kg^{-1}) 30 DAS in august month. The Minimum nitrate (418.6 mg kg^{-1}) 25 DAS in October month, phosphate (908.8 mg kg^{-1}) 25 DAS in April month, sulphate (473 mg kg^{-1}) 25 DAS in October month and magnesium (66.5 mg kg^{-1}) 25 DAS in April month (Chan-Navarrete at al. 2014 and Dapoigny at al. 2000).

Lettuce crops growing different conditions Cu, Mn, Zn and Fe mineral concentration ($\text{mg } 100\text{g}^{-1}$ fresh weight) of are shown in Fig 3. Lettuce grown in different growing seedling age and months under hydroponic systems showed non-significant effects ($P < 0.05$) on plant quality parameters viz. Cu, Mn, Zn and Fe content. Micronutrient content was significantly affected by the reproduction system of plant. While analysing the quality attributes of leafy Lettuce under hydroponic system exhibited the maximum mineral content Cu (0.17 mg kg^{-1}) 35 DAS in July month, Mn (1.18 mg kg^{-1}) 25 DAS in August month, Zn (1.89 mg kg^{-1}) 25 DAS in August month and Fe (6.29 mg kg^{-1}) 35 DAS in June month followed by Cu (0.169 mg kg^{-1}) 35 DAS in August month, Mn (1.17 mg kg^{-1}) 35 DAS in July month, Zn (1.73 mg kg^{-1}) 35 DAS in July month and Fe (6.24 mg kg^{-1}) 35 DAS in July month while minimum content was recorded in plants in Cu (0.11 mg kg^{-1}) 30 DAS in April month, Mn (0.78 mg kg^{-1}) and Zn (0.47 mg kg^{-1}) 35 DAS in April month and Fe (4.93 mg kg^{-1}) 25 DAS in April month. How much is absorbed depends on the concentration of nutrients in the solution near the roots, and this relationship is often modified by environmental variables such salt, oxygen, temperature, pH of the nutrient solution, light intensity, photoperiod, and air humidity. Consequently, the plant's requirements determine the need for minerals. (Kim *et al.* 2016)

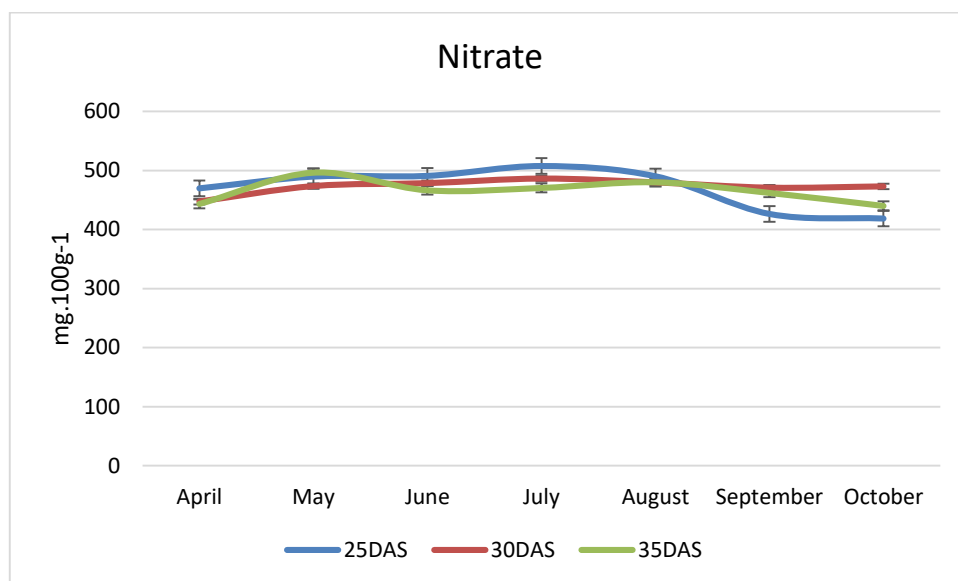


Fig. 4.17 Effects of seedling age and seasonal variations on nitrate content in lettuce crop grown in vertical hydroponic systems

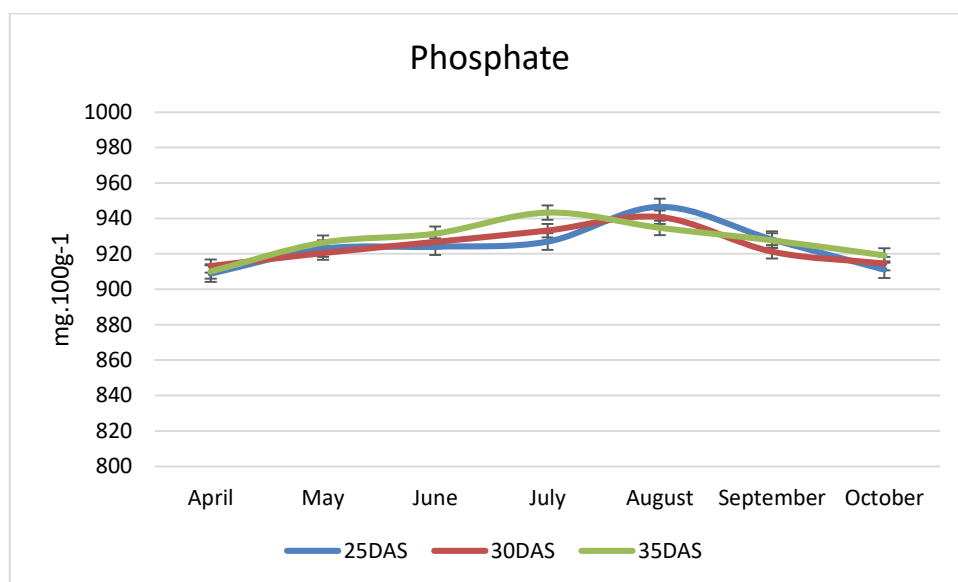


Fig. 4.18 Effects of seedling age and seasonal variations on Phosphate content in lettuce crop grown in vertical hydroponic systems

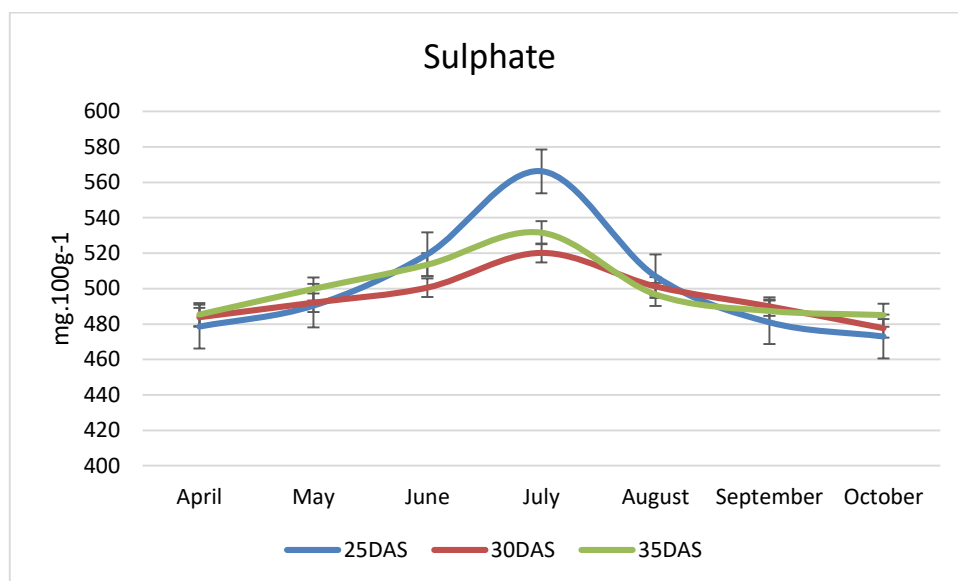


Fig. 4.19 Effects of seedling age and seasonal variations on Sulphate content in lettuce crop grown in vertical hydroponic systems

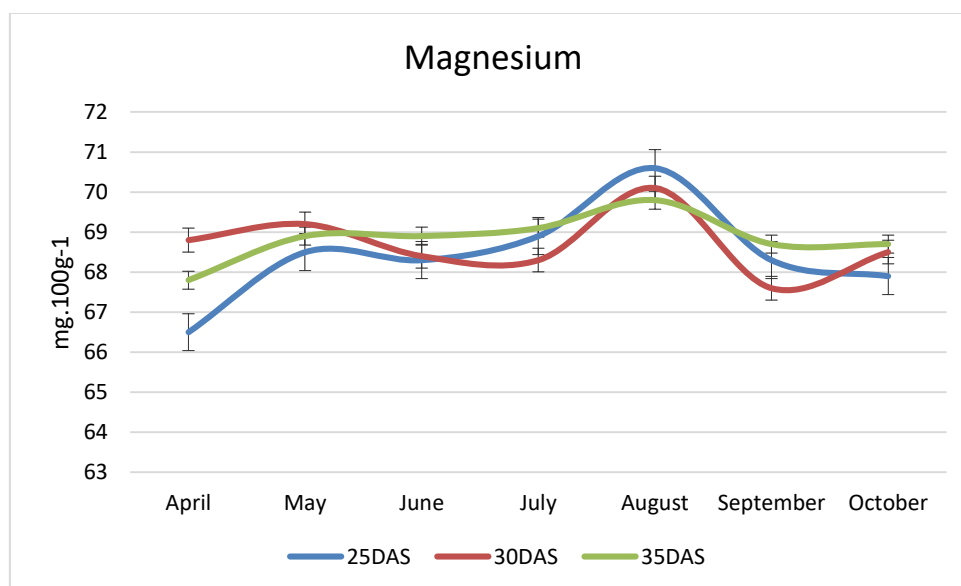


Fig. 4.20 Effects of seedling age and seasonal variations on Magnesium content in lettuce crop grown in vertical hydroponic systems

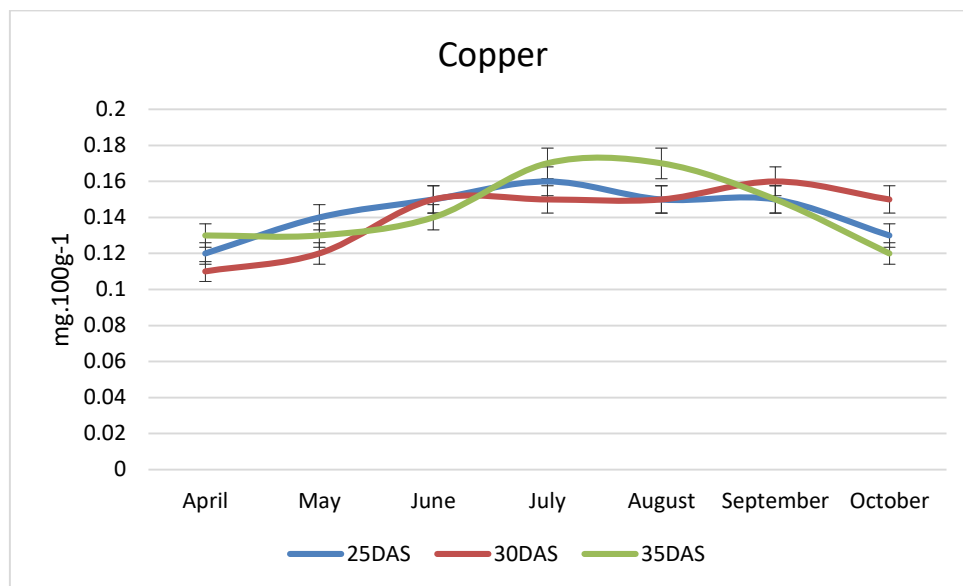


Fig. 4.21 Effects of seedling age and seasonal variations on Copper content in lettuce crop grown in vertical hydroponic systems

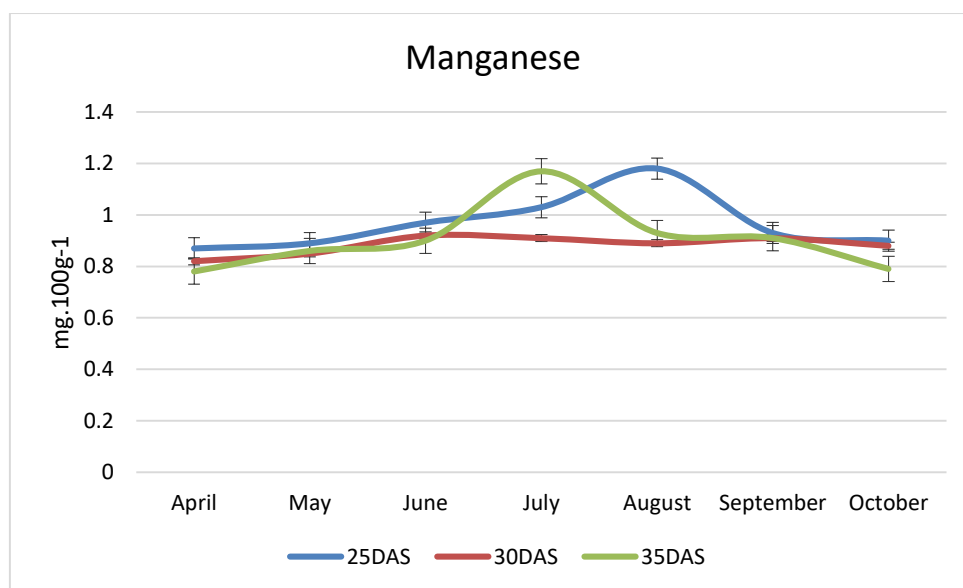


Fig. 4.22 Effects of seedling age and seasonal variations on Manganese content in lettuce crop grown in vertical hydroponic systems

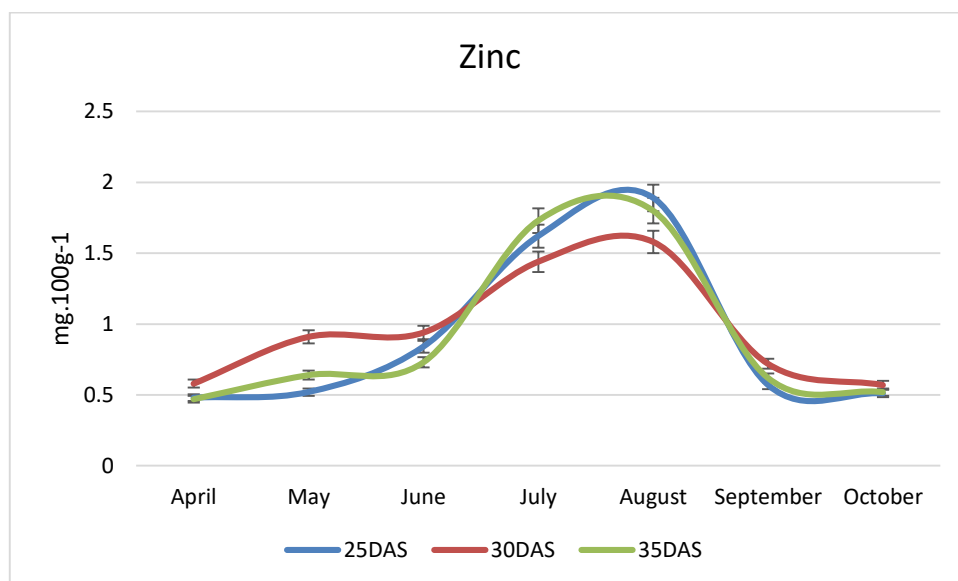


Fig. 4.23 Effects of seedling age and seasonal variations on Zinc content in lettuce crop grown in vertical hydroponic systems

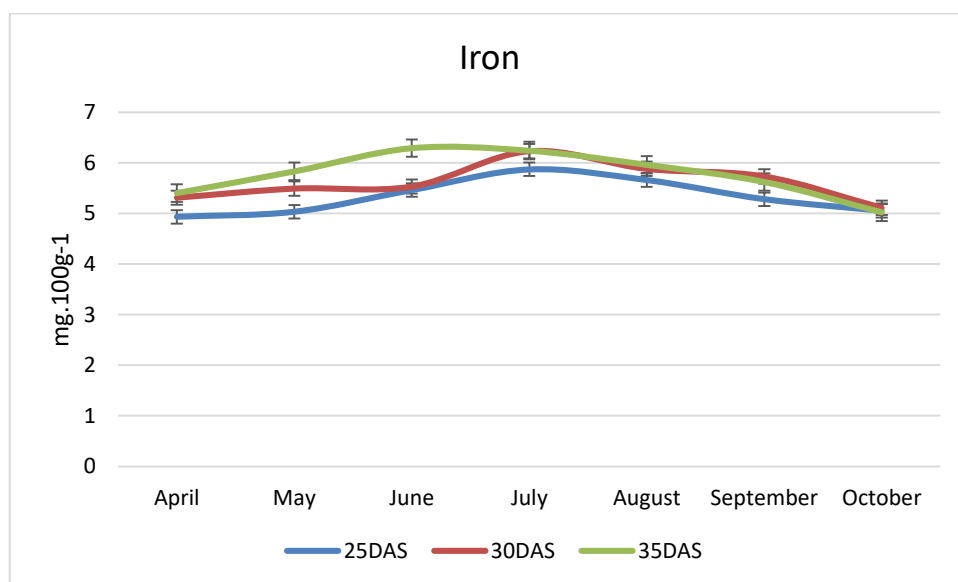


Fig. 4.24 Effects of seedling age and seasonal variations on Iron content in lettuce crop grown in vertical hydroponic systems.

4.3 Objective IVth. “To study yield and quality parameters of spinach and lettuce grown in vertical circulating hydroponic technique under greenhouse, open environment and room conditions”.

4.3.1 Plant growth and yield attributes of spinach and lettuce:

Table 2 compares the growth, morphology, and yield-related traits of spinach and lettuce grown in hydroponic NFT systems under various environmental growing conditions, including plant height, number of leaves, leaf area, fresh weight, and yield. The crops exhibited significant differences in above attributes grown in NFT system environmental condition compared. It was observed that the plant height of spinach grown in green house (25.0 ± 2.0 cm) was found maximum while followed by open condition (21.33 ± 2.08 cm) minimum plant height was found in room condition in both conditions (19.0 ± 1.0 cm). The higher number of leaves per. plant was recorded in green house grown circulated NFT system (15.0 ± 1.0) and the lowest number of leaves / plant was recorded in room condition (10.7 ± 1.5 b). The leaf area of green house with grown in NFT system (76.4 ± 3.7 cm²) was significantly higher ($P < 0.05$) than open condition (68.9 ± 4.06 cm²) and room condition (64.1 ± 9.4 cm²) grown crop. Because more leaves result in a greater photosynthetic response and more photosynthetic product, it might be achievable. Green house grown in NFT circulated system (52.1 ± 3.4 g and 3.23 ± 0.21 kg) exhibited maximum values for fresh weight gram per plant and yield kg m⁻² followed by Open condition grown in NFT circulated system (31.4 ± 2.5 g and 1.94 ± 0.15 kg) and lowest value of Room condition (28.5 ± 2.5 g and 1.77 ± 0.16 kg) at $P < 0.05$ in spinach crop (Gent, 2014 and Gent, 2017).

The plant height of lettuce observed in room condition (25.3 ± 1.5 cm) was found maximum while followed by green house (21.3 ± 1.5 cm) and minimum plant height was found in open condition (15.0 ± 1.0 cm). The higher number of leaves per plant was recorded in green house grown circulated NFT system (25.3 ± 1.5) and the lowest number of leaves /plant was recorded in room condition (9.7 ± 0.6 a). The leaf area of green house (68.4 ± 2 cm²) with grown in NFT system was significantly higher ($P < 0.05$) than open condition (63.3 ± 7.4 cm²) and room condition (45.6 ± 5.7 cm²) grown crop. It might be possible because higher number of leaves causes higher photosynthetic reaction leading to more photosynthetic product. Green house grown in NFT circulated system (38.3 ± 3.5 g and 2.38 ± 0.22 kg) exhibited maximum values for fresh weight gram per plant and yield kg m⁻² followed by Open condition grown in NFT circulated system (29.7 ± 2.1 g and 1.84 ± 0.13 kg) and lowest value of room condition (15.3 ± 2.5 g and 0.95 ± 0.16 kg) at $P < 0.05$. Green House grown in NFT system showed significant ($P < 0.05$) difference in lettuce plant yield (Brandenberger et al. 2007)

Table 4.25 Growth and yield attributing characters of lettuce and spinach grown in different environmental condition at harvest.

Growing Conditions	Green House	Open condition	Room condition
Spinach			
Plant Height (cm)	25.0±2.0b	21.33±2.08ab	19.0±1.0b
Leaf number plant ⁻¹	15.0±1.0b	12.0±1.0ab	10.7±1.5b
Leaf Area(cm ²)	76.4±3.7a	68.9±4.06a	64.1±9.4a
Fresh Weight (g plant ⁻¹)	52.1±3.4b	31.4±2.5a	28.5±2.5a
Yield (kg m ⁻²)	3.23±0.21b	1.94±0.15a	1.77±0.16a
Lettuce			
Plant Height (cm)	21.3±1.5b	15.0±1.0a	25.3±1.5c
Leaf number plant ⁻¹	13.3±0.6b	12.3±1.2b	9.7±0.6a
Leaf Area(cm ²)	68.4±2b	63.3±7.4b	45.6±5.7a
Fresh Weight (g plant ⁻¹)	38.3±3.5c	29.7±2.1b	15.3±2.5a
Yield (kg.m ⁻²)	2.38±0.22c	1.84±0.13b	0.95±0.16a

Data were shown in mean ± standard deviation (n = 9). Statistics show that the values in the same column with various letter values are significant by Duncan's test at $p \leq 0.05$.

This distinction is because of exceptional surroundings in case of hydroponic greenhouse cultivation to different conditions. Crops want appropriate surroundings for it's a hit growth. The handiest circumstance to attain appropriate surroundings for higher crop production is the hydroponic greenhouse cultivation. It is feasible to develop cereals, vegetables, fruits, fodder, flowers, condiments, and medicinal plant in hydroponic greenhouses (Khan, 2018). The initial assessments of the hydroponic in inexperienced residence manipulate approach display that it is ideal opportunity to the presently to be had strategies used for nutrient deliver and environmental circumstance with top best manufacturing of crops. (Saraswathi, *et al.*, 2018). Hydroponic greenhouse cultivation is higher choice with inside the feel of usage of inputs and progressed crop production and similar results show (Khan, 2018, Dufault *et al.* 2006 and Du Toit and Labuschagne 2007).

4.3.2 Sugar profiling and pigment contents of spinach and Lettuce

Plant Sugar profiling and total sweetness index of spinach as influenced by different growing condition like green house, open condition and room condition in NFT hydroponic system are described in Fig 3. In spinach, significant highest TSI (6708.95), fructose (3091.80 mg 100g⁻¹), glucose (2517.43 mg 100g⁻¹) and sucrose (158.0 mg 100g⁻¹) content was observed in green house NFT system followed by TSI (6264.76), fructose (6264.76 mg 100g⁻¹), glucose (2199.83 mg 100g⁻¹) and sucrose (148.7 mg 100g⁻¹) contain in open condition. Whereas, lowest TSI (5912.6), fructose (2853.8 mg 100g⁻¹), glucose (1951.6 mg 100g⁻¹) and sucrose (148.6 mg 100g⁻¹) content was recorded in room condition.

The lettuce crops grown in different growing condition like green house, open condition and room condition in NFT hydroponic system are described in Fig.4. In lettuce, significant highest TSI (2928.05), fructose (1320.33 mg 100g⁻¹), glucose (1123.97 mg 100g⁻¹) and sucrose (93.33mg 100g⁻¹) content was observed in green house NFT system followed by TSI (2756.17), fructose (1247.60 mg 100g⁻¹), glucose (1048.47 mg 100g⁻¹) and sucrose (87.93 mg 100g⁻¹) contain in open condition. Whereas, lowest TSI (2426.31), fructose (1079.70 mg 100g⁻¹), glucose (950.73 mg 100g⁻¹) and sucrose (84.20 mg 100g⁻¹) content was recorded in room condition. Somen *et al.* (2020) found comparable leafy viewable each lowering and general sugar content material turned into determined substantially better in NFT gadget than soil grown spinach. Total sugar content material of lettuce varies from 480 to 1970 mg 100g⁻¹ relying upon range and type (Mou. 2008). The carbohydrates production through plant is an important factor affected by CO₂, water and light. Our results are in agreement with reviews of Fillion and Kilcast (2002) who confirmed effective correlation among soluble sugar content material and first-class of veggies and d described that that soluble sugar.

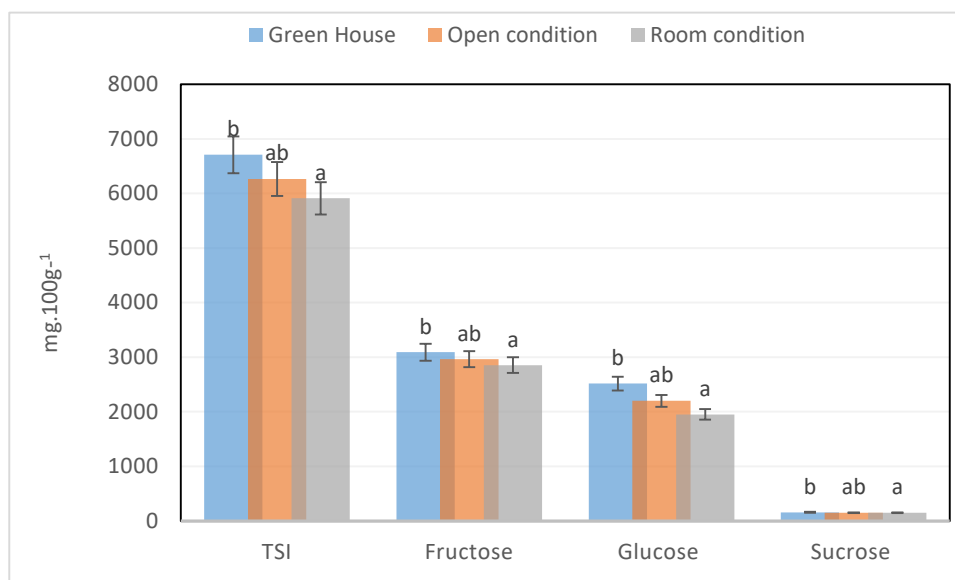


Fig. 4.25 Glucose, fructose, sucrose and total sweetness index of spinach grown in different environmental condition at harvest.

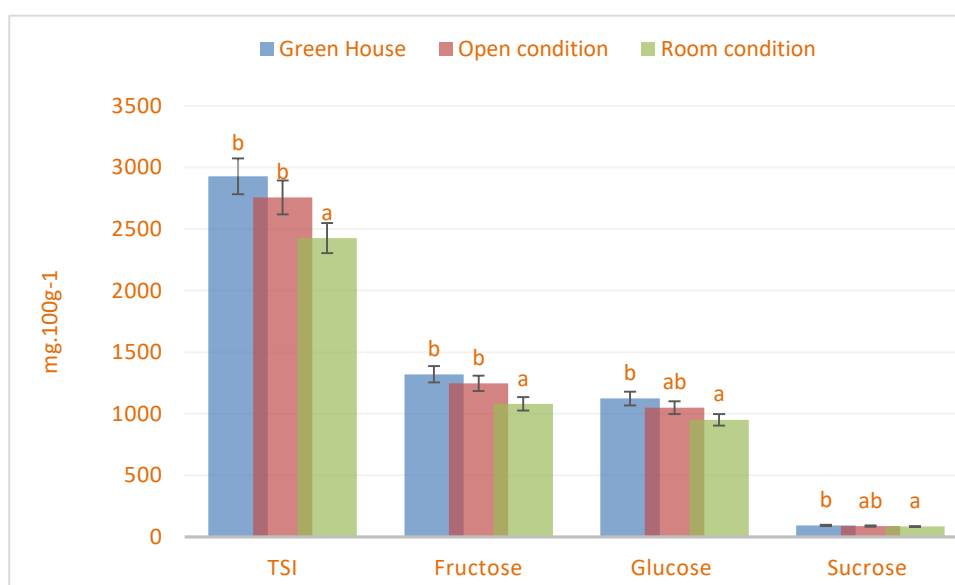


Fig. 4.26 Glucose, Fructose, Sucrose and Total Sweetness Index of lettuce grown in different environmental condition at harvest.

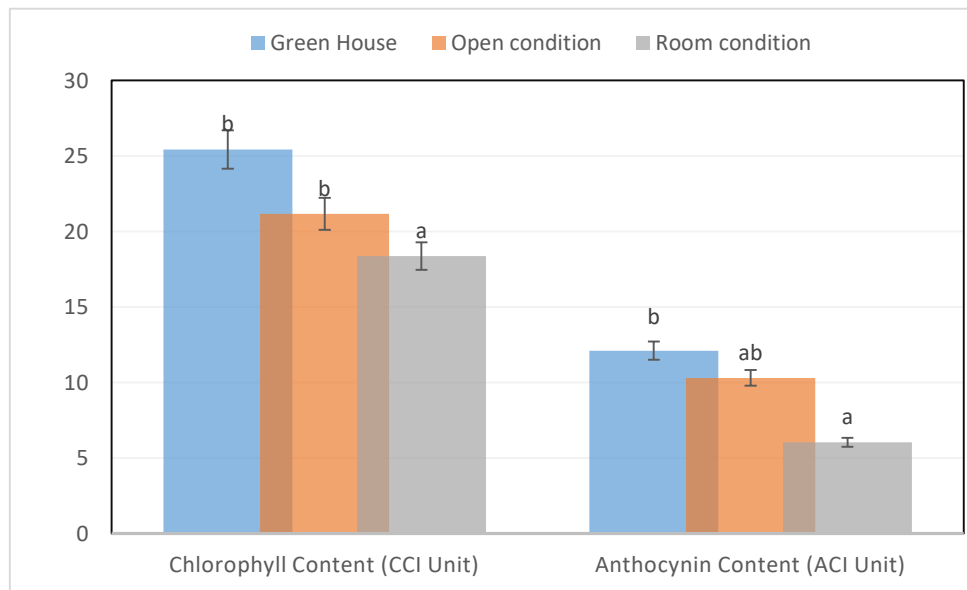


Fig. 4.27 Plant leaf pigment anthocyanin and chlorophyll contents of spinach grown in different environmental condition at harvest.

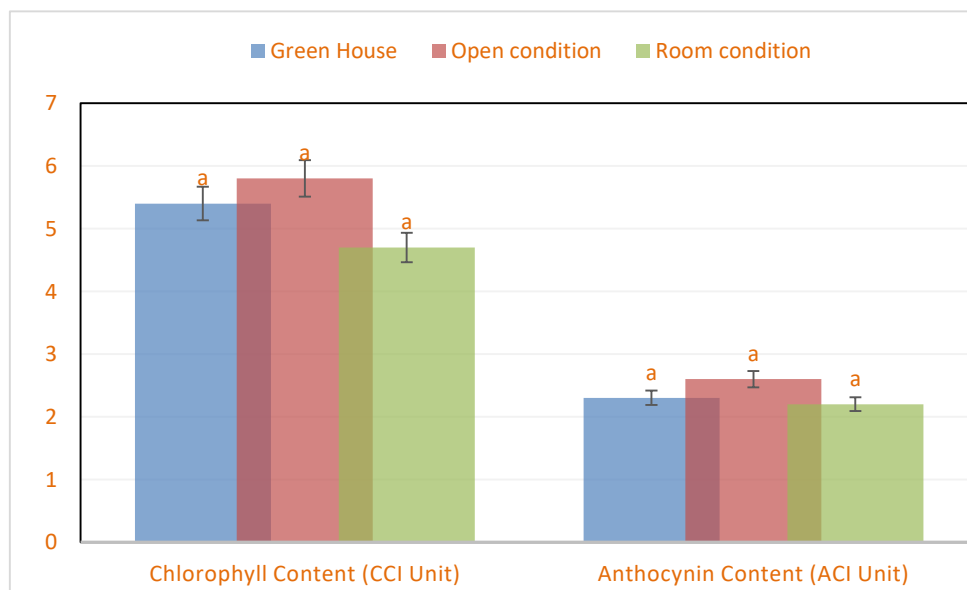


Fig. 4.28 Plant leaf pigment anthocyanin and chlorophyll contents of lettuce grown in different environmental condition at harvest.

and crude fiber are carbohydrates that have an effect on the beauty and crispness of leafy vegetables. Plant leaf pigment anthocyanin and chlorophyll contents of spinach as influenced by various growing condition NFT hydroponic system described in fig 5. The greenhouse NFT circulated system exhibited significantly highest chlorophyll content (25.4 CCI) and anthocyanin content (12.1 ACI) followed by open condition (21.2 CCI) and (10.3 ACI) with NFT system. The spinach in room condition showed lowest chlorophyll content and anthocyanin content (18.4 CCI) and (6.0 ACI).

The present in spinach anthocyanin and chlorophyll contents grow in various condition in verticality NFT hydroponic system of lettuce described in fig 6. The open condition NFT circulated system exhibited non-significantly highest chlorophyll content (5.8 CCI) and anthocyanin content (2.6 ACI) followed by green house (5.4 CCI) and (2.3 ACI). The room condition showed lowest chlorophyll content and anthocyanin content (4.7 CCI) and (2.2 ACI). Significant variations in lettuce and spinach output quality between various growing conditions were also noted by Matthew *et al.* (2011), somen, *et al.* (2021) with agree results.

4.3.3 Macro and Micro nutrients of spinach and Lettuce

Spinach grown in different growing condition NFT hydroponic systems showed significant effects ($P < 0.05$) on plant quality parameters viz. nitrate, phosphate, sulphate calcium and magnesium content of leaves (Fig. 7). Macro primary and secondary nutrient content was significantly impact by the growth and producer of plant system. When examining the qualitative characteristics of leafy spinach grown in a greenhouse, the NFT system showed the maximum nitrate (997.09), phosphate (904.92), sulphate (311.04) calcium (83.34) and magnesium (97.65) content followed by open condition with NFT system exhibited the maximum nitrate (964.44), phosphate (828.17), sulphate (295.05) calcium (78.43), and magnesium (93.31) content. Minimum nitrate (895.30), phosphate (775.17), sulphate (276.80), calcium (67.20) and magnesium (89.04) mg kg⁻¹ content of spinach was recorded in room condition.

Lettuce cultivated under various conditions on plant quality measures, such as the nitrate, phosphate, sulphate, calcium, and magnesium content of leaves (Figs. 8), NFT hydroponic systems demonstrated significant effects ($P < 0.05$). The production and expansion of the plant system had a major impact on the macro primary and secondary nutrient content. While analysing the quality attributes of leafy lettuce greenhouse with NFT system exhibited the maximum nitrate (521.1), phosphate (965.9), sulphate (578.2) calcium (78.6) and magnesium (64.4) content followed by open condition with NFT system exhibited the maximum nitrate (495.0), phosphate (925.1), sulphate (506.7) calcium (69.2), and magnesium (53.1) mg kg⁻¹ content. Minimum nitrate. (435.1), phosphate (909.2), sulphate (465.8), calcium (64.2) and magnesium (50.2) mg kg⁻¹ content of spinach was recorded in room condition (Delaide at al. 2016, Bottoms at al. 2012 and Broadley at al. 2000).

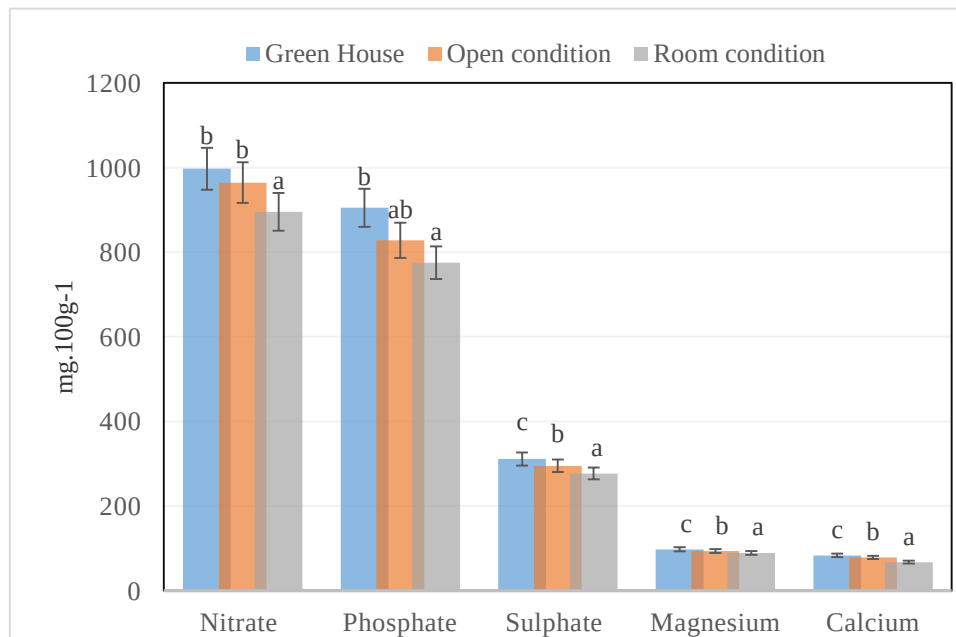


Fig. 4.29: Macro (nitrate, phosphate, sulphate calcium and magnesium) content and Micro nutrient contents of spinach grown in different environmental condition at harvest

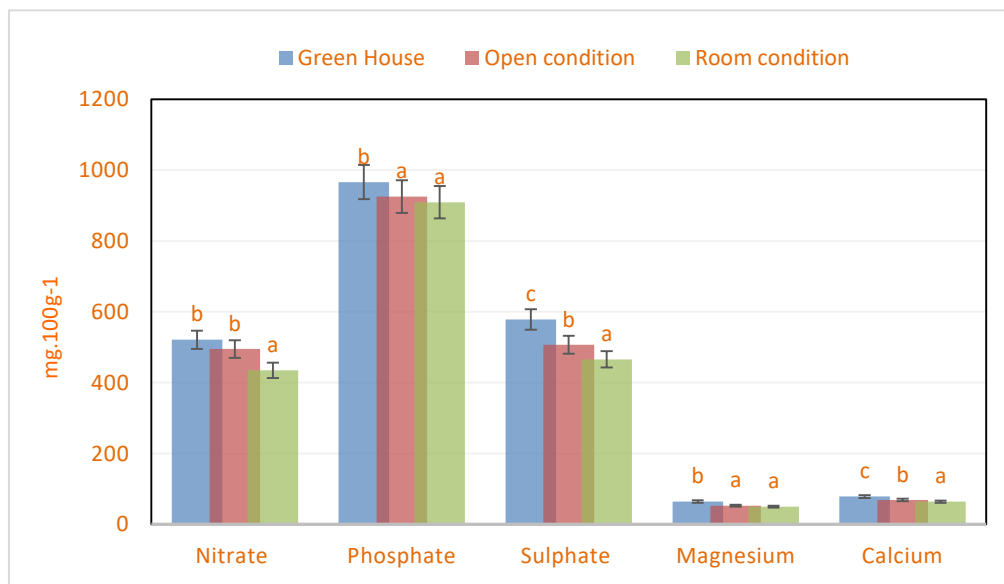


Fig. 4.30: Macro (nitrate, phosphate, sulphate calcium and magnesium) content and Micro nutrient contents of lettuce grown in different environmental condition at harvest

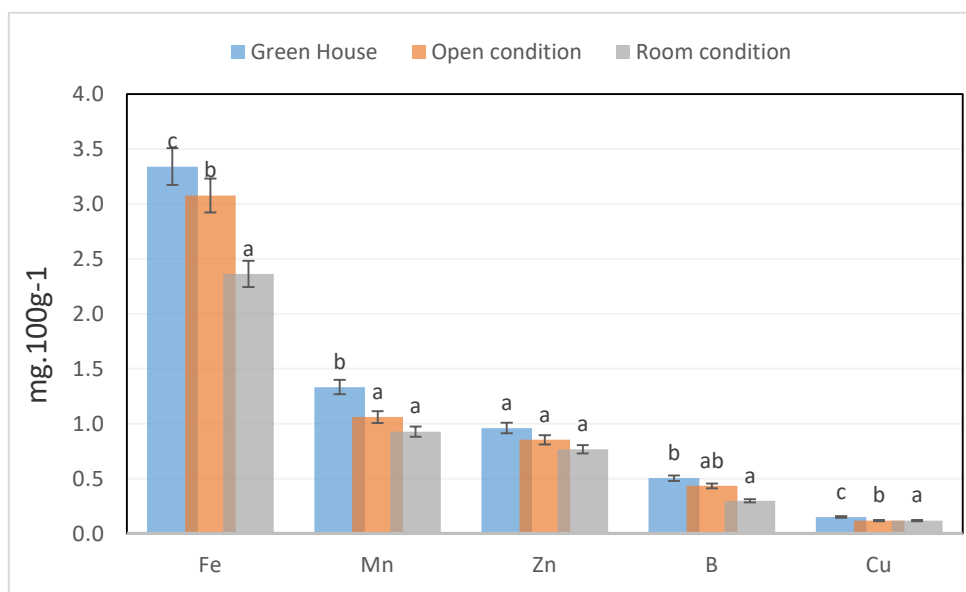


Fig. 4.31: Micro nutrient (Fe Mn, Zn, B and Cu) contents of spinach grown in different environmental condition at harvest

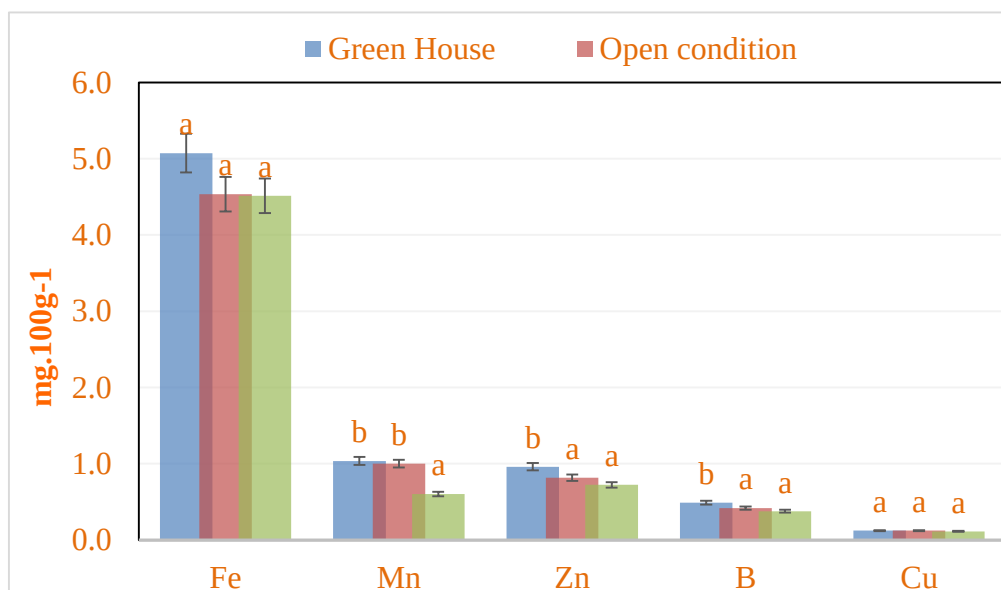


Fig. 4.32: Micro nutrient (Fe Mn, Zn, B and Cu) contents of lettuce grown in different environmental condition at harvest

This assessment confirmed that there may be distinction among developing conditions. This distinction is because of favourable environment in case of hydroponic greenhouse cultivation compare to other cultivation condition. To attain the best quality, its miles essential to deliver main nitrate, phosphate, sulphate calcium and magnesium ions for plant boom with better attention in produces yield. (Lee *et al.* 1995, Lee *et al.* 2017, Kwon *et al.* 2021 & Khan, 2018)

Spinach crops growing different conditions Fe Mn, Zn, B and Cu mineral concentration (mg 100g⁻¹ fresh weight of fruit) of are shown in Fig 9. Spinach grown in different growing condition NFT hydroponic systems showed significant effects ($P < 0.05$) on plant quality parameters viz. Fe, Mn, B and Cu content and non-significant in Zn content in spinach leaves. Micronutrient content was significantly affected by the reproduction system of plant. While analysing the quality attributes of leafy spinach greenhouse with NFT system exhibited the maximum Fe (3.34), Mn (1.33), Zn (0.96), B (0.50) and Cu (0.15) content followed by open condition with NFT system exhibited the Fe (3.08), Mn (1.06), Zn (0.85), B (0.43) and Cu (0.12⁻¹) content while minimum content was recorded in plants harvested from room condition Fe (2.36), Mn (0.93⁻¹), Zn (0.77), B (0.30) and Cu (0.12) per mg kg in spinach crop.

In Fig. 10, lettuce cultivated under various conditions is depicted, together with their Fe, Mn, Zn, B, and Cu mineral concentrations (mg 100g⁻¹ fresh weight of fruit). lettuce cultivated under various conditions On plant quality measures, such as Mn, B, and Zn content, NFT hydroponic systems shown substantial effects ($P < 0.05$), while the effects on Fe and Cu content in spinach leaves were not significant. The plant's reproductive system has a substantial impact on micronutrient content. While analysing the quality attributes of leafy spinach greenhouse with NFT system exhibited the maximum Fe (5.07), Mn (1.04⁻¹), Zn (0.96), B (0.49) and Cu (0.12) content followed by open condition with NFT system exhibited the Fe (4.54), Mn (1.00), Zn (0.82), B (0.42) and Cu (0.12⁻¹) content while minimum content was recorded in plants harvested from room condition Fe (4.51), Mn (0.60), Zn (0.72), B (0.38) and Cu (0.11) mg kg⁻¹. Optimising the usage of nutrients in hydroponic vegetation is key, on account that plant nutrient intake has come to be one of the maximum sizeable environmental in greenhouses situation with better mineral nutrition uptake in plant produce yield. Sanjuan, (2017). Green house technique, in particular with inside the creating with of mineral vitamins and better yield manufacturing with rich exceptional mineral nutritional. Martin, *et al.* (2019) and Cumo *et al.* (2018).



Fig. 4.33: Diagrammatic representation of hydroponic cultivation of leafy Spinach



Fig.4.34: Diagrammatic representation of hydroponic cultivation of leafy Lettuce

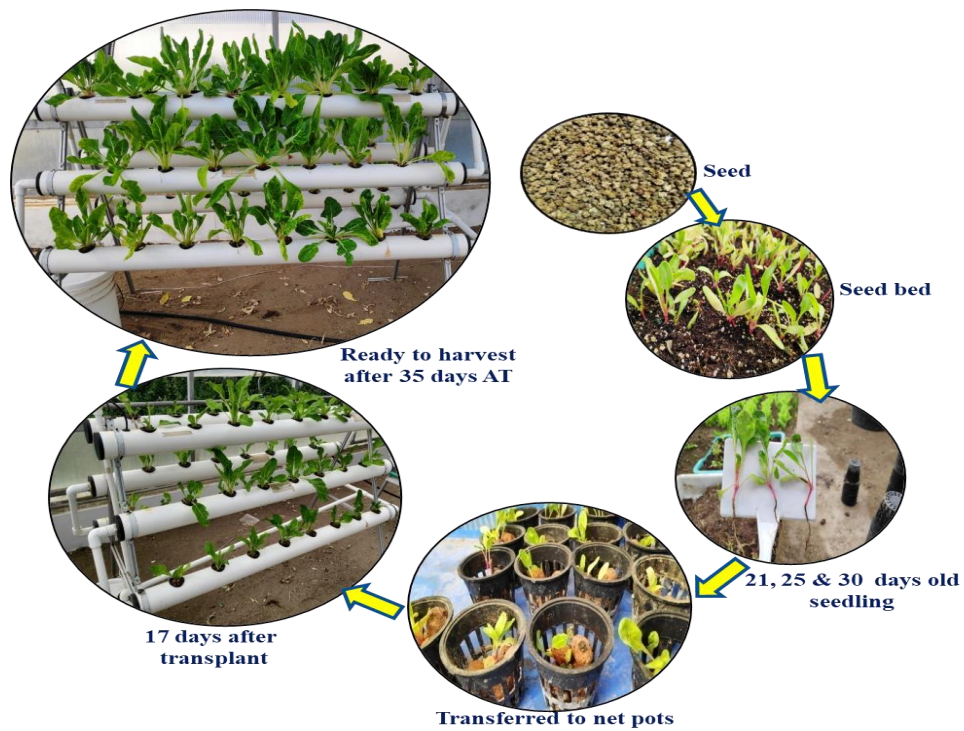


Fig. 4.35: Diagrammatic representation of hydroponic cultivation of leafy Lettuce

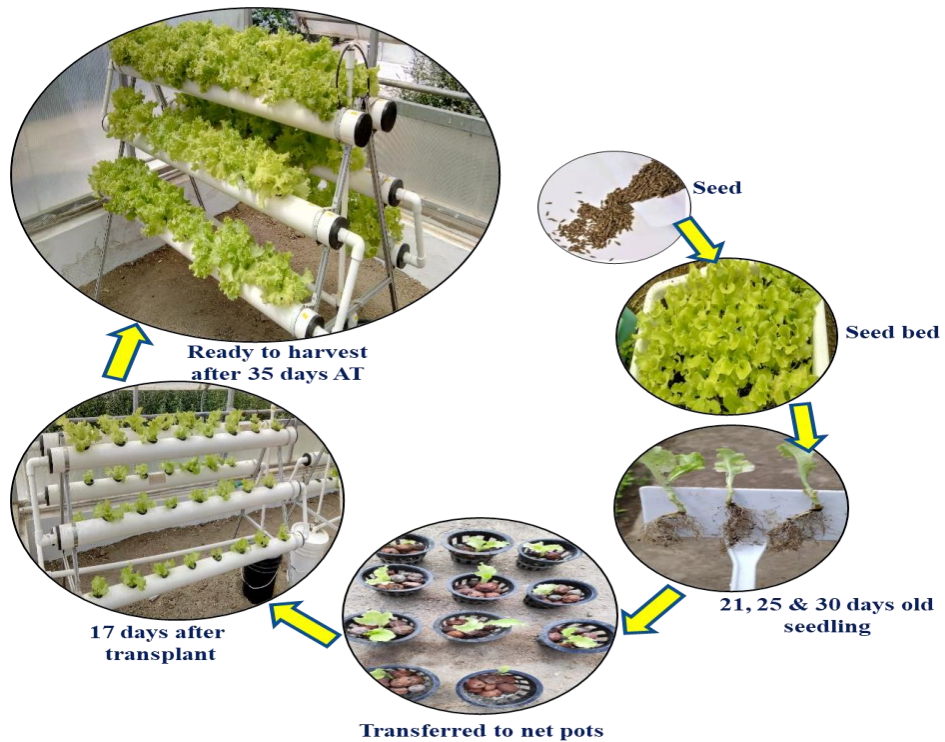


Fig. 4.36: Diagrammatic representation of hydroponic cultivation of leafy Lettuce

CHAPTER 5: SUMMARY AND CONCLUSION

5.1 Summary

Currently being conducted is a study with the “Evaluation of Circulatory and Non-Circulatory Hydroponic Techniques on Yield and Quality of Spinach and Lettuce at Cold Desert Trans Himalayan Region of India” was conducted during 2018-2019, 2019-2020 and 2020-2021 at the Vegetable Research Unit, Defence Institute of High-Altitude Research, DRDO, Leh-Ladakh (latitude, longitude, 34°08'23"N, 77°34'21"E. and Altitude 3333 meter) with the following objectives.

1. To study growth and yield attributing parameters of spinach and lettuce grown under hydroponic systems and soil cultivation.
2. Comparative evaluation of bio-chemical and mineral nutrition parameters of spinach and lettuce grown under hydroponic techniques and soil grown system.
3. To assess effects of seedling age and seasonal variations on yield and quality of spinach and lettuce in vertical circulated hydroponic system.
4. To study yield and quality parameters of spinach and lettuce grown in vertical circulating hydroponic technique under greenhouse, open environment and room conditions.

Three replications of a crop like spinach and lettuce were used in the experiment, which was entirely randomized in its design. In this dissertation an approach was initiated to understand the hydroponic leafy vegetable crops production round the year at Cold Desert Trans Himalayan Region of India. Also the research was inducted to understand the increasing yield and quality production. Variation growth and yield characteristics, as well as nutrient status and quality criteria, were recorded during the experiment during harvesting phases of the crop growth and standardization of modified hydroponic media. The results obtained from investigation are summarized below:

1. 1st and 2nd Objective-In this study we have shown that lettuce and spinach grown by hydroponics especially by Vertical NFT system showed higher yield and better quality, rapid harvest and high nutritional content in respect to macro, micro nutrients and Sugar. The crop yield production result show significantly higher in all crops yield per meter square in hydroponic compared to traditional system. The crops yield recorded lettuce 293% and

spinach 294 higher yield in hydroponics system compared to traditional system. Hydroponics can be explored for growing vegetables round the year especially for growing leafy greens. The hydroponic systems may be provided to forward and remote area of Trans Himalayas region for growing fresh vegetables where cultivated land and availability of the water is the most limiting factors for crop production.

2. 3rd Objective- In this study we have The Spinach seedling age and seasonal variations ($p < 0.05$) significant difference in plant growth, morphology & yield attributing characters in 30 days old seedling in month of July in circulated hydroponic system compare to all seedling ages and season. The lettuce seedling age and seasonal variations ($p < 0.05$) significant difference in plant growth, morphology & yield attributing characters in 25 days old seedling in month of June in circulated hydroponic system compare to all seedling ages and season. The Spinach and Lettuce seedling age and seasonal variations no-significant difference ($p < 0.05$) in leaf Nitrate, phosphate, sulphate and Magnesium contents characters in in circulated hydroponic system compare to all seedling ages and season. The spinach and Lettuce seedling age and seasonal variations ($p < 0.05$) no significant difference in leaf Fe, Zn, Mn and Cu contents in circulated hydroponic system compare to all seedling ages and season. The spinach and Lettuce seedling age and seasonal variations ($p < 0.05$) no significant difference in leaf Glucose, Fructose, Sucrose and Total Sweetness Index contents in in circulated hydroponic system compare to all seedling ages and season
3. 4th Objective- To study growth and yield attributing parameters of spinach grown under in circulating hydroponic technique under greenhouse, open environment and room conditions. The crops grown Spinach and lettuce exhibited significant improvement in growth and yield in NFT system with greenhouse compared to other conditions. The higher content of Calcium, Magnesium, Nitrate, phosphorus, sulphur: B, Cu, Mn, Ni, Zn and Fe elements and Glucose, fructose, sucrose and total sweetness index ($\text{mg } 100\text{g}^{-1}$ Fresh leaf) was observed in hydroponically grown spinach and lettuce especially in NFT system with greenhouse compared to other conditions

5.2 Conclusions:

Overall, these findings showed that the NFT hydroponics system offers effective nutrient management, increasing lettuce and spinach crop output. Hydroponics promises to be the technology of near future in world where people in urban areas can also grow their own crops for

consumption with limited space and free from any toxic chemicals and pesticide residues. Lettuce and spinach grown in hydroponics especially in Vertical NFT system showed higher yield and better quality, rapid harvest and higher nutritional content in respect to macro, micro nutrients and sugar profiling compared to soil grown system in high altitude cold desert Ladakh region. Overall, NFT system of hydroponics provides better nutrient management leading to increased production in lettuce and spinach. Hydroponic system should be promoted in arid and semi-arid areas where availability of irrigation water as well as arable land is very scarce for successful production of nutrient rich vegetables.

Hydroponics technology is a major solution to increase crop yield and quality of crops with limited agricultural land. It also works efficiently if there is any water or energy shortage in the area. Vertical hydroponics promises to be the technology of near future in India where people in urban areas can also grow their own crops with limited space. This study can conclude that hydroponic leafy vegetable production can act as a sustainable alternative to conventional soil-based crops production for Cold Desert Regions. To grow crops like cucumber, strawberry and summer squash in hydroponics, further research is required so as to figure out the suitable nutrient and optimum conditions to improve the production. We can set up hydroponic crop production system in polycarbonate green house, local green house and underground room conditional throughout the year when the land is unfertile. The temperature can be maintained manually by operating ventilators that are south-facing with west frame. Supplementary lighting and heating can be provided depending on location. In order to produce vegetables or fruits with fewer resources and contribute to a world food system that is self-sufficient, hydroponics can be used. To find choices for soilless growing media, such as reusable fertilizer solutions, more study is required. Within a circular economy, it is critical to find strategies to increase the sustainability of hydroponic systems overall.

5.3 Scope of study: Utilizing hydroponics improves nutrient use efficiency and reduces nutrient losses. Compared to normal farming, there is a 75–85% water conservation rate.

5.4 Suggestions for future work

In this investigation only two crops (lettuce and Spinach), Future research on fruit vegetable crop for in urban area and desert area.

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