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Hydroponic vs. soil cultivation of lettuce and spinach: A study in a polycarbonate greenhouse at high altitudes in the Trans-Himalayan region

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Abstract

This study compared the hydroponic and soil cultivation systems for lettuce and spinach production in India's cold desert, high-altitude Trans-Himalayan region. Hydroponic cultivation is a soilless technique that provides fresh vegetables in regions with environmental stress and limited arable land. The experiment was conducted in hydroponic structures designed for leafy vegetable cultivation, including vertical and horizontal circulated nutrient film technique (NFT), non-circulated systems, and soil cultivation in an open, naturally ventilated double-layer polycarbonate greenhouse in Ladakh, India. Results showed that lettuce and spinach grown in the vertical circulated NFT system had significantly better plant growth characteristics such as plant height, number of leaves, leaf area, fresh weight, and yield than horizontal NFT, non-circulated, and soil systems. Moreover, fresh produce from vertical and horizontal NFT systems had higher nitrate content, soluble sugar content, and total sweetness index, indicating better crispiness of the produce. Mineral nutrient contents (Ca, Mg, B, Cu, Mn, Zn, Fe, and Ni) were also higher in the circulated NFT system compared to other systems studied. Thus, this study demonstrated that lettuce and spinach grown in NFT systems produced significantly higher yields with better nutritional quality than soil-grown systems in the Trans-Himalayan region. Hydroponic systems are recommended for successfully producing nutrient-rich vegetables in areas with limited water and arable land. This is the first demonstration of hydroponic systems in high-altitude cold desert conditions for growing leafy greens, and it has promising implications for sustainable agriculture.

Key words: Hydroponic, leafy vegetables, Ladakh, NFT

Introduction

Soil is not necessary for plant growth and survival. Any medium that contains enough nutrients to support the plant acts as soil or ground surface. Hydroponics grows plants in water without soil using mineral solution. India's high-altitude cold desert region of Leh-Ladakh has harsh climates, a short agriculture season, and six months of landlocked winter. This region is known for its high radiation, low humidity, low soil fertility, and one cropping season (May to October). Hydroponics is used to grow fresh leafy vegetables in extreme high-altitude conditions to meet human needs. However, fresh vegetable production in this region is difficult year-round. Fresh leafy vegetable cultivation in cold deserts is hindered by limited land, saline water, low fertility, and barren topography. Fresh leafy vegetable crops face a major challenge in quality production. Lettuce (*Lactuca sativa*) is a popular leafy vegetable grown in commercial hydroponic systems using the nutrient film technique. Vertical hydroponic farming boosts production per unit area (Touliatos *et al.,* 2016). Lettuce is rich in vitamin K, A, pro-vitamin A, β-carotene, folate, and iron. Lettuce is popular with burgers and fresh salad in hotels and restaurants. Spinach leaves are eaten fresh, frozen, canned, chopped, or dehydrated. Spinach is nutritious when fresh, frozen, steamed, or quickly boiled. An excellent source of vitamins A, C, K, magnesium, manganese, iron, and folate. Riboflavin, pyridoxine, vitamin E, calcium, potassium, and dietary fibre are abundant in spinach (FAO). Hydroponics allows for early maturity (marketable yield) and uniform plant growth of leafy vegetables. High yields and soil-borne disease-free crops eliminate harmful chemicals and provide nutritious produce (Sharma *et al.,* 2018). Leh-Ladakh agriculture struggles with water shortages, forcing many vegetable growers to switch to hydroponics. Most soil and environmental factors' complexities and interference are avoided with this technique, improving experiment control. Hydroponics uses mineral nutrient solutions in water to grow plants without soil. Hydroponics in the greenhouse yielded more vegetables than soil-based pots (Du Toit and Labuschagne, 2007). Hydroponic cultivation is becoming more popular worldwide because it efficiently uses natural resources, especially in areas where soil and water limit plant growth, helping to combat climate change and produce high-quality food (Sardare *et al.,* 2013).

A study was conducted to assess and compare the efficacy of hydroponic cultivation systems, specifically vertical and horizontal circulated Nutrient Film Technique (NFT), against traditional soil cultivation for lettuce and spinach production in the high-altitude cold desert conditions of India's Trans-Himalayan region. The study aims to evaluate plant growth characteristics, yield, and nutritional quality, with a focus on parameters such as plant height, number of leaves, leaf area, fresh weight, nitrate content, soluble sugar content, total sweetness index, and mineral nutrient concentrations.

Materials and methods

Experimental site: In the present experiment, lettuce (var. Grand rapid) and spinach (var. Delta) were grown hydroponically and conventionally in soil under double-layer polycarbonate greenhouse conditions during the summer season of 2019-20 at Vegetable Research Unit, Defence Institute of High-Altitude Research (DIHAR), DRDO, Leh-Ladakh (latitude: 34°'08'23 "N; longitude: 77°34'21 "E and altitude: 3330 meter). During the experimental trial, the minimum and maximum temperature was 18^0C and 34^0C, respectively, with a relative humidity of 35-65% inside the greenhouse.

Hydroponic system: Various hydroponic structures were specially designed for leafy vegetables cultivation. The dimensions of the 3-tier vertical circulated nutrient film technique (NFT) system were 160×90×150 cm (L×W×H) with 46 net pot and reservoir of 20 litre capacity. For the horizontal circulated NFT system, the dimension was 140×60 ×90 cm with 28 net pot and reservoir of 20 litre capacity and for the non-circulated system it was 55×40×12 cm with 12 net pots and a reservoir of 8-litre capacity. In each net pot, two seedlings were transplanted using clay balls as supporting media. Water and nutrients were re-circulated through the hydroponic NFT unit from the reservoir using a submerged pump with a flow rate of 8 litres per minute.

Preparation of nutrient solution: Plant nutrients used in hydroponics are dissolved in water and are mostly in inorganic and ionic forms. Using different chemical combinations, 17 essential elements that plants require for their growth were supplied. 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 2 mL of each DIHAR-I and DIHAR-II nutrient solution was mixed with 1 liter of Tube well water. The pH and EC values of the hydroponics nutrient solution were measured routinely using a pH and EC meter (Hach, USA). The pH range of hydroponics solution varies between 6.0-6.5 for optimum growth of plants. NaOH and HCl were added to obtain the optimum pH of the nutrient solution range (Trejo and Gomez, 2012).

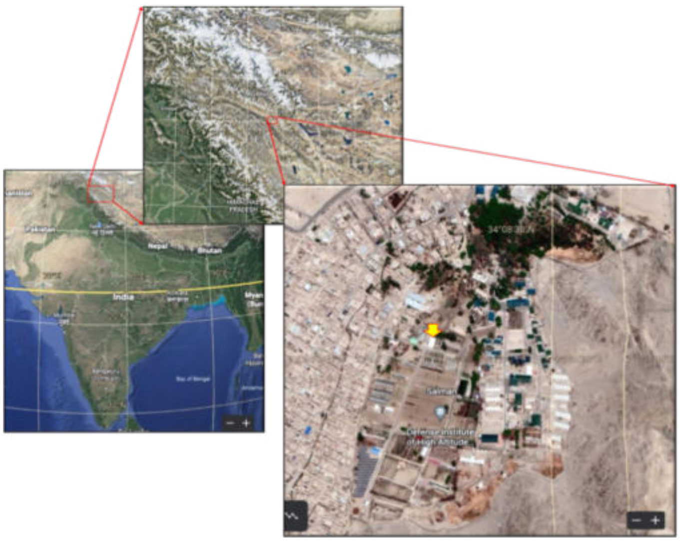

Fig. 1. Experimental site (India, Ladakh and Leh)

Table 1. Modified Hoagland nutrient solution composition

Component	Stock Solution (g/L)
DIHAR-I	
$Ca(NO_3)_2*4H_2O$	202
Iron EDDHA (Iron Chelate)	5.6
DIHAR-II	
KH_2PO_4	136
KNO_3	133
$MgSO_4*7H_2O$	58.1
H_3BO_3	2.89
$ZnSO_4*7H_2O$	0.22
$MnCl_2*4H_2O$	0.20
$CuSO_4*5H_2O$	0.08
$NaMoO_4*2H_2O$	0.12

Crop management: In tray, the lettuce and spinach seeds were grown in seed germination media comprising cocopeat, vermiculite and perlite (5:2:1). Regular watering was done after sowing. Seedlings were ready to transplant after 24 days and uniform seedlings were transplanted in different hydroponic systems and soil condition. The seedlings were placed into net pots (two seedlings) 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 intervals in hydroponic systems. Lettuce and spinach were harvested after 35days after transplantation.

Measurements of growth and yield parameters: Nine randomly selected plants were taken from each experimental site (different hydroponic systems and soil conditions) for measuring plant height. At the time of transplanting, thirty-six plants were tagged. Growth and yield parameters were recorded in each hydroponic system as well as soil conditions during harvesting stage. Plant height and root length was measured with measuring scale; fresh weight was measured with weighing balance (Presica, XB 220A) and yield was expressed in kg m^{-2}.

Determination of pigment content and leaf area: Chlorophyll and anthocyanin content in lettuce and spinach were determined by portable handheld chlorophyll and anthocyanin meter respectively (CCM-200 plus and ACM-200 plus, ADC Bioscientific, UK). Each plant's physiologically active leaves were collected and each leaf's area was measured using a scanner based leaf area meter (Biovis PSM – L2000).

Determination of anions and sugar profiling of lettuce and spinach: For determination of anions and sugar profiling of lettuce and spinach, anions (nitrate, sulphate and phosphate) and sugar (glucose, fructose and sucrose) standards were purchased from Sigma Aldrich (St. Louis, MO, USA). All aqueous solutions were prepared using ultrapure Type 1 water from Direct-Q (Millipore Waters, USA) with a resistivity of 18.2 MΩ.cm. Nitrate, phosphate, sulphate and sugar profiling (glucose, fructose and sucrose) were determined using ion chromatography (IC) system (930 compact IC Flex, Metrohm, Switzerland). For anion (nitrate, phosphate and sulphate) analysis MetroSepA Supp 5-250/4.0 anion column was used and for determinations of soluble sugars, RCX-30-7µm-250/4.1mm (Hamilton, USA) column was used. In mobile phase, 3.2mM Na_2CO_3, 1mM

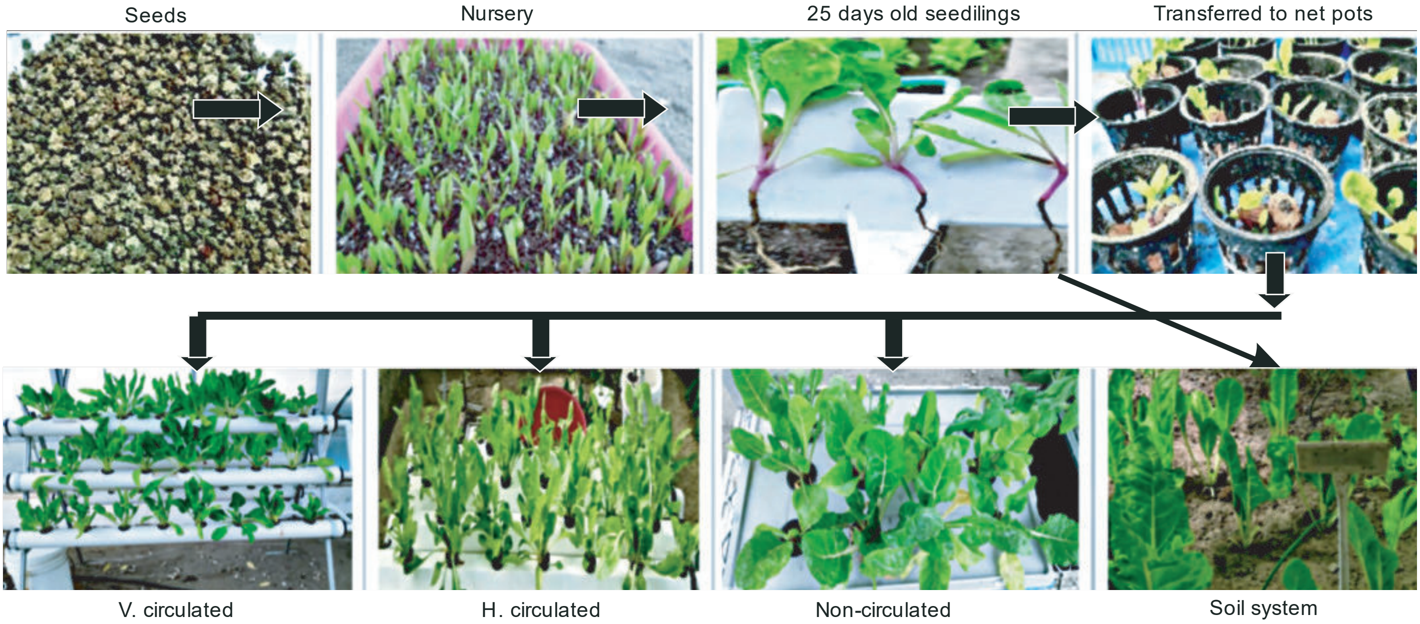

Fig. 2: Diagrammatic representation of hydroponic cultivation of leafy Spinach

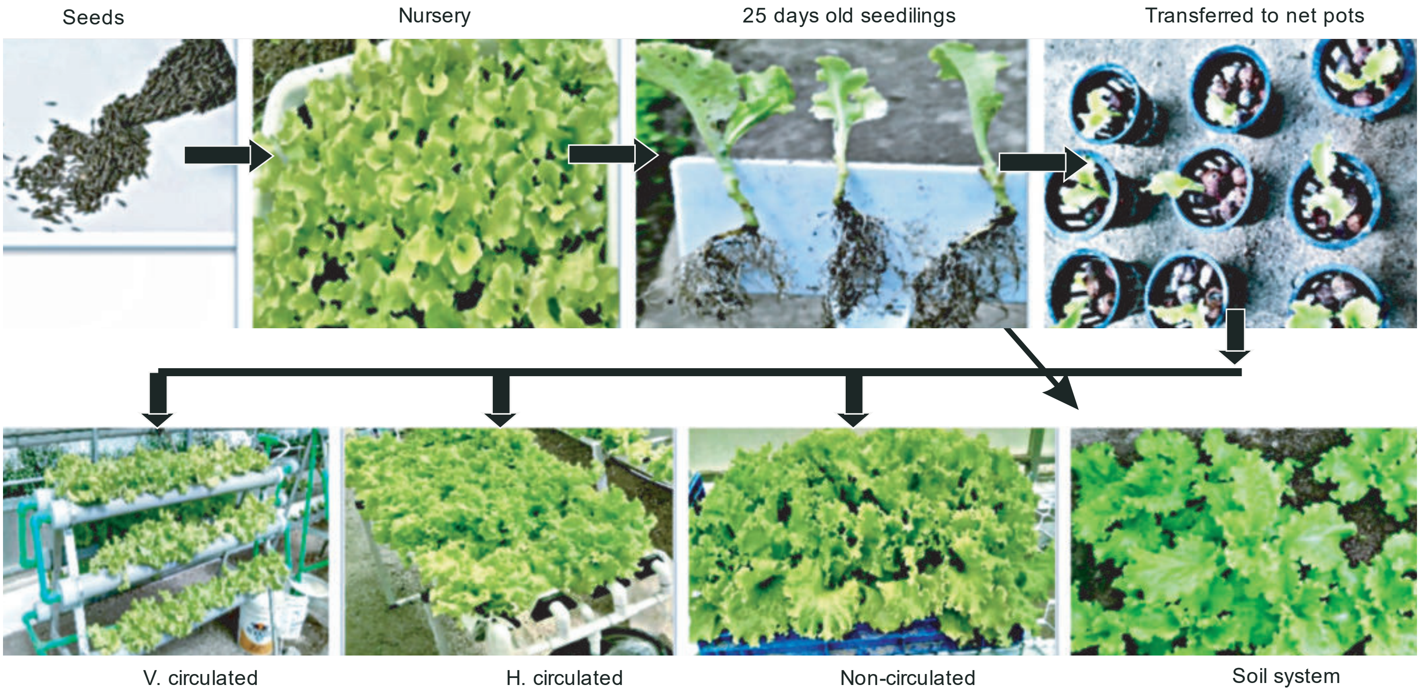

Fig. 3: Diagrammatic representation of hydroponic cultivation of leafy lettuce

$NaHCO_3$ and 5% acetone was used as eluent for anion analysis with flow rate of 0.7 mL min^{-1}. 100mM H_2SO_4 solution was used as the suppressor solution for anion analysis. For sugar analysis, 0.1M NaOH was used as eluent with flow rate of 1.0 mL min^{-1}. Nitrate, phosphate and sulphate were detected using a conductivity detector and soluble sugars using an amperometric detector (Acharya *et al.,* 2021).The total sweetness index (TSI) was determined by the concentration and sweetness coefficient of each soluble sugar and was calculated using the equation by Magwaza and Opara (2015)

$$TSI = 1.50 \times \text{fructose} + 0.76 \times \text{glucose} + 1.00 \times \text{sucrose}.$$

Mineral nutrient analysis: The mineral content of the lettuce and spinach samples was determined using the AOAC (1990) methods. Calcium (Ca), Magnesium (Mg), Manganese (Mn), Iron (Fe), Copper (Cu), Boron (B), Nickel (Ni) and Zinc (Zn) were determined by using standards (Sigma Aldrich) of respective elements. About 200 mg of the sample was first digested in a microwave digestion system (Topwave, Analytik Jena, Germany) with 8 mL of acid mixture (6.0 mL nitric acid and 2.0 mL HCl). The digested samples were then diluted with distilled water to 50 mL mark. After obtaining the digest, aliquots of the clear digest were used for mineral analysis by Inductively Coupled Plasma Optical Emission Spectroscopy (ICPE-9000, Shimadzu, Japan) and Atomic Absorption Spectrophotometer (ZEEnit 700P, Analytik Jena, Germany). The concentrations of minerals in fresh lettuce and spinach samples were expressed in mg per 100 g.

Statistical analysis: All experimental data were expressed as mean ± standard deviation using statistical analysis with SPSS

22 (SPSS Corporation, Chicago, Illinois, USA) and MS excel 2019. Differences between mean values were evaluated using one way (ANOVA) analysis of variance. The differences were compared using the Duncan's test with a significance level of 5% (Pallant, 2020).

Results and discussion

Growth and yield attributing characters of lettuce and spinach: The present study examines the plant growth, morphology, and yield characteristics of lettuce and spinach cultivated in different hydroponic systems, including vertical and horizontal circulated systems, non-circulated systems, and soil systems. Table 2 summarizes the results of the experiment. The lettuce displayed a significant difference ($p<0.05$) in plant height and yield in vertically circulated NFT system compared to horizontal NFT, non-circulated hydroponic system and soil-grown crop. The highest lettuce and spinach plant height was obtained in the vertical NFT system (26.0 cm and 30.33 cm) followed by the horizontal NFT system in spinach (26.11 cm) and non-circulated system in lettuce (19.2 cm), respectively. Meanwhile, leafy greens grown in the soil system recorded the shortest plant height in both crops. The root length exhibited the highest values in horizontal NFT (21.6 cm) for lettuce and vertical NFT (28.11 cm) for spinach, and the lowest root length was recorded in the soil system (9.8 cm and 9.78 cm for lettuce and spinach, respectively). Similarly, the highest number of leaves per plant for lettuce (20.8 and 19.3) and spinach (24.56 and 22.22) was recorded in the vertical NFT system and horizontal NFT system, respectively. Whereas maximum leaf area was found in the vertical NFT system (lettuce: 102.2 $cm^{-2}$and spinach: 88.89 cm^{-2}) which was significantly higher ($P<0.05$) than soil-grown vegetables. The leafy vegetables yield per meter square was significantly higher in the vertical NFT system (lettuce: 3.2 $kg.m^{-2}$ and spinach: 3.57 $kg.m^{-2}$) followed by horizontal NFT, non-circulated system and the lowest yield was recorded in soil-grown crops (lettuce: 0.70 $kg.m^{-2}$ and spinach: 0.96 $kg.m^{-2}$). When we compared lettuce and spinach, the growth and yield attributing characteristics of both hydroponic lettuce and soil system were lower than the spinach crop.

The plant height of both crops depended on the proper nutrient supply to the plant. The plants grown in a hydroponic system are provided with nutrients in balanced quantities, resulting in better plant height. Similar results were also observed by Li *et al.* (2018). Both lettuce and spinach crops produced fresh weight per plant in the order of vertical NFT system>horizontal NFT system>Non-circulated system>soil system. The hydroponic system produced a significantly higher fresh weight of leafy greens than soil-grown crops. The fresh weight depends on higher plant height, number of leaves, leaf area, and root system, contributing to better yield per plant in the NFT system. Our results are similar to Ercan and Bayyurt (2014) and Ciriello *et al.* (2019) findings. Previous studies also demonstrated that nutrients are the primary factors that influence plant growth and biomass production in hydroponic culture (Sublett *et al.,* 2018). Leaf number, leaf area and fresh biomass incurred significant interaction (Pannico *et al.,* 2019; Kratky, 2010). The growth study indicated that a vertical hydroponic system did have the potential to enhance lettuce and spinach yield significantly. The advantage of hydroponic cultivation is water conservation and increased productivity per unit area. Hydroponic crop cultivation substantially reduces water loss and increases nutrient use efficiency compared to conventional cultivation (Sapkota *et al.,* 2019; Al Shrouf, 2017; Öztekin *et al.,* 2018; Ferguson *et al.,* 2014).

Table 2. 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 (cm^2)	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 are shown in mean ± standard deviation (n = 12). The values with the different letter within the same column are statistically significant by Duncan's test at $P \leq 0.05$

The sugar profiling, total sweetness index (TSI) and pigment contents in lettuce and spinach: The soluble sugar in lettuce and spinach is mainly composed of glucose, fructose and sucrose, among which fructose has the highest sweetness. Glucose, fructose, sucrose and total sweetness index in lettuce and spinach were influenced by different hydroponic systems and soil conditions, as depicted in Table 3. The lettuce grown in vertical NFT system exhibited highest glucose (1172.8 $mg.100g^{-1}$), fructose (1384.2 $mg.100g^{-1}$), sucrose (92.3 $mg.100g^{-1}$) and total sweetness index (3059.9), followed by horizontal NFT and non-circulated system, alongside lowest glucose (761.4 $mg.100g^{-1}$), fructose (908.8 $mg.100g^{-1}$), sucrose content (74.9 $mg.100g^{-1}$) and total sweetness index (2016.8) in lettuce grown in soil.

Similar results were also observed in spinach regarding sugar accumulation in the leaves. Specifically, spinach grown in the vertical circulated system showed significantly higher values ($P<0.05$) for glucose content (2749.3 $mg.100g^{-1}$), fructose content (3187.3 $mg.100g^{-1}$), sucrose content (160 $mg.100g^{-1}$), and total sweetness index (7030.5) compared to spinach grown in soil, which had glucose content of 1649.5$mg.100g^{-1}$, fructose content of 2694.8 $mg.100g^{-1}$, sucrose content of 121.5 $mg.100g^{-1}$, and total sweetness index of 5417.4. It is worth noting that glucose accumulation in spinach was almost 2.3 times higher compared to lettuce grown under similar conditions. Spinach with the highest TSI was observed under the vertical NFT system and compared with lettuce, TSI of spinach grown in the vertical NFT system was significantly increased by approximately 2.3 times. The glucose, fructose, sucrose and total sweetness index of lettuce exposed to different lighting modes was also studied by Chen *et al.* (2019). Factors regulating sugar accumulation in vegetable tissues include photosynthetic rate, an increase in plant production requiring a high atmospheric CO_2 fixation rate, optimum nutrition and water, which is achieved by increasing sugar in the plant body. A recent study indicated that lighting treatments can decrease NO_3 content and simultaneously increase total soluble solids and sugar contents (Guo *et al.,* 2019). The plants grown hydroponically and enriched with organic forms of iodine, specifically 3.5-diiodosalicylic acid, were observed to exhibit increased levels of glucose, fructose, and total sugars in their yield, as noted by Sularz et al. (2020).

Table 3. Glucose, fructose, sucrose and total sweetness index in lettuce and spinach crops produced 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

The values with the different letter within the same column are statistically significant by Duncan's test at $P \leq 0.05$

Anthocyanin and chlorophyll content in lettuce was found to be significantly (P<0.05), highest in the vertically circulated system (2.86 ACI and 4.98 CCI) and lowest (2.72 ACI and 4.12 CCI) was recorded in soil system. Whereas anthocyanin and chlorophyll content in spinach show significantly similar result. Maximum anthocyanin and chlorophyll content in lettuce and spinach was found in the vertical NFT system and the lowest values were recorded in soil system. It may be due to the plant's genetic variability and cultivar, specific growing condition and greenhouse that may affect the plant pigment contents of leafy vegetables (Caldwell and Britz, 2006; Sapkota *et al.,* 2019; Öztekin *et al.,* 2018). Anthocyanin and chlorophyll content in leafy greens is also affected by sunlight and day length in hydroponics systems and soil cultivation under greenhouse conditions or room conditions (Acharya *et al.,* 2021). This comprehensive growth study demonstrates that lettuce grown hydroponically is of better quality than that produced in soil (Lei and Engeseth, 2021).

The content of nitrate, phosphate, sulphate in lettuce and spinach: Lettuce and spinach grown in different hydroponic systems and soil conditions showed significant effects (P<0.05) on plant quality parameters viz. nitrate, phosphate and sulphate content of leaves. On the other hand, growing conditions had no significant effects (P>0.05) on the pigment contents of lettuce and spinach as influenced by different hydroponic systems and soil conditions (Table 4).

Nitrate content was significantly affected by the production system. While analysing the quality attributes of leafy lettuce, the vertical NFT system exhibited the maximum nitrate content (5416.7 mg.kg^{-1}) while the minimum content (3669.3 mg.kg^{-1}) was recorded in plants harvested from soil system. Similarly, the highest nitrate content of spinach (12488.7 mg.kg^{-1}) was recorded in the vertical NFT system, reaching significant level compared to any other treatment in the present study. The highest nitrate content of spinach (12488.7 mg.kg^{-1}) was recorded in the vertically circulated system, though it was significantly similar with the horizontal circulated system and the minimum nitrate content (8040.4 mg.kg^{-1}) was recorded in soil condition. Similarly, significantly (P<0.05) maximum values phosphate content (9570.0 mg.kg^{-1}) in lettuce was found in the vertical circulated system and minimum phosphate content (8094.8 mg.kg^{-1}) was recorded in the soil system.

Table 4. Anions and leaf pigment contents in lettuce and spinach crops 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 are shown in mean ± standard deviation (n = 12). The values with the different letter within same column are statistically significant by Duncan's test at $P \leq 0.05$

Nitrate content of spinach grown in vertical NFT system was found about 2.3 times higher than lettuce with same growing condition. Minimum nitrate content of spinach was recorded in soil condition. In hydroponic cultivation, nutrient solution concentration had significant effects on nitrate contents (Öztekin *et al.,* 2018). Nitrate level in the plant is the most frequent factor that affect plant growth and productivity. Leafy vegetables can be considered as the main source of human nitrate intake (Ranasinghe and Marapana, 2018; Sularz *et al.,* 2020). Similarly, significantly (P<0.05) maximum values phosphate content in lettuce and spinach was found in vertical NFT system and minimum phosphate content was recorded in soil system. Phosphorus forms parts of important life-sustaining molecules and leafy vegetables are considered to be very common source of phosphorus (Oladeji and Saeed 2018). Likewise, highest sulphate content was observed in vertical NFT system followed by horizontal NFT, non-circulated and soil condition in both lettuce and spinach. Overall, phosphate and sulphate content accumulation was higher in lettuce compared to spinach and significantly higher nitrate content was recorded in spinach than in lettuce. Similar results were also recorded by Frezza *et al.* (2005); Ezziddine *et al.* (2021). Plant primary and secondary nutrients content was significantly affected by the hydroponic production system compared to soil. Siomos *et al.* (2001) reported that teh crops harvested from soilless culture had higher nitrate, phosphorus and potassium content compared with soil culture. The plant growing periods optimize supply for nutrients with oxygen in hydroponic systems. Its helps to increasing nutritional quality of plant production and yield of crops (Blok *et al.,* 2017a; Blok *et al.,* 2017b).

Mineral nutrients in lettuce and spinach: The nutrient contents of lettuce and spinach grown in hydroponics and soil system is outlined in Table 5. It was observed that almost all nutrients were significantly higher (P<0.05) in NFT hydroponic systems compared to soil-grown lettuce and spinach. In lettuce, nutrients

Table 5. Mineral Ca, Mg, Zn, Fe, Cu, Mn, B and Ni contents ($mg.100g^{-1}$) in lettuce and spinach crops produced 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

The values with the different letter within same column are statistically significant by Duncan's test at $P \leq 0.05$.

except Cu, were significantly higher in vertical NFT system than in non-circulated and soil conditions. In lettuce, nutrients like Ca, Mg, B, Ni and Zn were found to be significantly highest in vertical circulated system (Ca 80.47, Mg 65.74, B 0.51, Ni 0.07 and Zn 1.02 $mg.\ 100g^{-1}$) compared to other conditions. Cu and Fe concentrations were non-significant recorded (Range between Cu 0.12 to 0.13 and Fe 4.16 to 5.22 $mg.\ 100g^{-1}$) in all growing conditions and Mn concentration was observed to be similar in vertical (1.06 $mg.100g^{-1}$) and horizontal (1.02 $mg100g^{-1}$) circulated systems. The nutrients lower value was found in soil system (Ca 62.37, Mg 49.0, B 0.25, Cu 0.12, Fe 4.16, Mn 0.38, Ni 0.05 and Zn 0.57 $mg.\ 100g^{-1}$).

The vertical circulated system showed significantly higher levels of nutrients (B 0.52, Cu 0.19, Mn 1.48, Ni 0.05, and Zn 0.97 $mg.\ 100g^{-1}$) in spinach compared to other conditions. The concentrations of calcium (Ca), magnesium (Mg), and iron (Fe) nutrients were found to be significantly similar in both the vertical (Ca 84.41, Mg 101.36, and Fe 3.47 $mg.\ 100g^{-1}$) and horizontal (Ca 78.50, Mg 97.04, and Fe 3.16 $mg.\ 100g^{-1}$) circulated systems. The soil system contains minimum amounts of nutrients. The present study reveals that the nutrient contents (Ca, Mg, B, Cu, Mn, Ni, Zn, and Fe elements) in lettuce and spinach were higher in hydroponic systems and lower in soil systems.

In lettuce, all minerals except Mn and B showed no significant difference between non-circulated and soil systems. In spinach, NFT-grown spinach exhibited the highest leaf nutrient content, while soil-grown spinach showed the lowest. Leafy greens like lettuce and spinach produced in hydroponic and soil systems displayed varying nutritional qualities. Hydroponically grown lettuce and spinach were found to be more nutritious compared to those grown in soil. The current experimental findings are consistent with the findings of Frezza et al. (2005) and Blasco (2011). The current findings show that lettuce and spinach had higher mineral Ca, Mg, B, Cu, Mn, Ni, Zn, and Fe contents ($mg.100g^{-1}$) in NFT hydroponic systems than in soil. Hydroponic technology can manage nutrient, water, and temperature to produce high-quality, soil-compatible vegetable crops. Increasing growth solution compositions (macro and micronutrient) does not always improve yield and quality in leafy vegetables. Increasing hydroponic solution EC 1.0 to 4.0 dS^{-1} proportionally increased leafy lettuce mineral concentrations (Sublett *et al.,* 2018). Lettuce and spinach grown in hydroponics, especially in Vertical NFT system showed higher yield and better quality, rapid harvest and higher nutritional content regarding macro, micronutrients and sugar profiling compared to soil-grown systems in high altitude cold desert Ladakh region. Overall, NFT hydroponics system provided better nutrient management, leading to increased production in lettuce and spinach. Hydroponic system should be promoted in arid and semi-arid areas where the availability of irrigation water as well as arable land is very scarce for the successful production of nutrient-rich vegetables.

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