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Comparative Analysis of Hydroponically and Soil-Grown Lettuce

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Abstract: Hydroponics has emerged as a prominent methodology in contemporary agricultural practices. However, there is uncertainty regarding the equivalence in quality between vegetables grown in hydroponic systems and those cultivated in soil. In the present study hydroponically and soil grown lettuce was compared for plant height, number of leaves, leaf length, leaf width, fresh and dry weight of root and shoot, moisture content, ash, total phenolics, flavonoids, antioxidant activity, chl a, chl b and β-carotene. For this romain lettuce was grown in soil and laboratory constructed NFT hydroponic system filled with Hoagland's solution for 35 days. Hydroponically grown lettuce records significantly higher values for plant height (hydro 27.85cm: soil 20.47cm), root length (hydro 21.52cm: soil 14.02cm), number of leaves (hydro 32.0: soil 19.4cm), leaf length (hydro 19.45cm: soil 15.96cm), leaf width (hydro11.23cm: soil 8.98cm), shoot Fresh weight (hydro 116.74g: soil 88.09g), root fresh weight (hydro 28.89g: soil 4.90g). On the other hand, total phenolics, flavonoid, antioxidant activity, chl a, chl b and β-carotene was recorded higher for soil grown lettuce. No significant difference was recorded in ash content while the moisture content was recorded 1.84% more in hydroponically grown lettuce. This study presents the initial thorough comparative analysis revealing that hydroponically cultivated lettuce is superior in growth characteristics but does not exhibit equivalent nutrient quality to that of lettuce cultivated in soil.

Keywords: Hoagland's nutrient solution • Hydroponics • Lettuce • Soil-grown.

Introduction

Lettuce, scientifically known as *Lactuca sativa* L., is a leafy vegetable which is a member of family Asteraceae. Lettuce is a vegetable of cool-season which flourishes within temperature ranges of 7 to 24°C (Sublett et al 2018). The nutritional profile of lettuce is exceptional, boasting high levels of vitamin C, dietary fiber and essential minerals (Mulabagal et al 2010). Historical records indicate the utilization of lettuce as a therapeutic remedy for a variety of diseases such as gastrointestinal issues, inflammation, pain, and urinary tract infections owing to its abundant secondary metabolites like terpenoids, flavonoids, and phenols (Noumedem et al 2017).

Hydroponic is a process of suspending roots in nutrient solutions so that plants effortlessly absorb nutrients and optimize their ability to grow tissue, ultimately maximizing their energy (Sardare & Admane 2013). This technique offers several advantages over soil-based farming, including enhanced nutrient control and efficiency. In hydroponics, essential nutrients are directly provided to plants in optimal proportions, ensuring efficient uptake and utilization. Conversely, soil-grown crops depend on the nutrient content and variability of the soil, which may require additional management practices such as fertilization and soil amendments. The system under consideration is categorized within the domain of soilless cultivation methodologies, wherein mineral-rich solutions are employed to deliver essential sustenance directly to plants, rather than relying on nutrients sourced from soil (Sambo et al 2019). The controlled environment in hydroponics facilitates optimal nutrient availability, pH, and oxygen levels, enabling plants to allocate more energy towards above-ground growth. The absence of soil-borne pathogens and pests in hydroponics reduces the risk of diseases, enhancing overall crop health and productivity. Soil-based farming, on the other hand, benefits from natural soil properties, including microbial communities that contribute to nutrient cycling, soil structure, and plant interactions (Jones 2016).

This research paper aims to conduct a comprehensive comparative analysis of hydroponically grown and soil-grown crops, shedding light on the advantages and suitability of each approach. By evaluating its growth and yield factors we can gain insights into the optimal utilization of these cultivation methods. This research will contribute to the ongoing discourse on innovative agricultural practices and assist stakeholders in making informed choices regarding crop cultivation methods.

Materials and Methods

Study site: The present investigation was carried out under controlled environmental conditions at the Department of Seed Science & Technology, H.N.B. Garhwal University, Srinagar Garhwal, Uttarakhand, India, (latitude: 30.2278° N, longitude:78.8015° E, altitude: 540 m above mean sea level) during the period spanning from October to November, 2023.

Planting material: These seeds were procured from Sakata Seed Pvt Ltd, located in Haryana, India. Prior to sowing, seeds were sterilized using a 70% ethanol solution for a duration of 45 seconds. Following this, the seeds were germinated in small net cups. Upon the development of two verdant leaves, seedlings were selected based on uniform size and transferred to hydroponic systems.

Hydroponic components: The hydroponic system configuration encompassed the utilization of plastic pipes with a total system length of 6.09m and a pipe diameter of 3 inches. A 25L plastic bucket was used as the reservoir for the modified Hoagland's nutrient solution (initial pH 6.5 ± 0.3; electrical conductivity of 1.60 ms/cm) (Plate 1). The nutrient solution was refreshed every three days. An air pump operating within a voltage range of 165-220 V/50 Hz was employed to aerate each hydroponic pipe. The system was connected to four horizontal pipes, with a total of eight seedlings planted at 10 cm distance within each pipe. The roots of the plants were consistently kept submerged in a stagnant nutrient solution. In order to uphold ideal conditions, a permeable air stone was placed in the hydroponic system to aerate the solution. The pH level of the nutrient solution was meticulously controlled within the specified range of 5.5 to 6.5.

Soil cultivation: To cultivate lettuce in soil, the first step was to get seedlings ready in plastic trays that were a certain size. A 2:1 mixture of soil and farmyard manure was used to fill these trays (Fig 1). After transplanting, the full crop was harvested 35 days later. Within the parameters of the experiment, ten lettuce plants were chosen at random for additional analysis from each system.

Fig 1. Schematic representation of hydroponic and soil grown system.

Measurement of plant morphology and growth characteristics:

Ten plants were chosen at random for the purpose of measurement and nutrient analysis from each of the growth mediums.

Determination of moisture and Ash: The determination of moisture % was conducted through employment of the oven drying method, which adheres to the Official Methods of Association of Official Analytical Chemists (AOAC, 2000). The calculation of moisture content was then ascertained through the following formula:

$$\% \, Moisture = \left(1 - \frac{M \, dried \, sample}{M \, fresh \, sample}\right) \text{ x } 100$$

Ash content was also determined in accordance with the AOAC method (1995, 900.02 A) and subsequently, the percentage of ash was calculated as:

$$\text{Ash } \%= \frac{Mashed \, sample - Mtare of crucible}{Msample/(1-\%moisture)} \text{ x } 100$$

Chlorophyll a, b and β-carotene (Wellburn 1994): The chlorophyll content was estimated by Wellburn's method (Wellburn 1994). For this 0.25 grams of fresh leaves were extracted using a mortar and pestle in 50 ml of 80% methanol to extract chlorophyll and beta-carotene. The absorbance at 663 and 645 nm of supernatant's was taken by using spectrophotometer to measure the amount of chlorophyll. Similarly, absorbance at 470 nm was taken to determine the amount of carotene. The levels for carotene, chlorophyll a, and chlorophyll b were then calculated using particular equations-

Chlorophyll a (mg/mL) = 12.7 A663 - 2.69 A645
Chlorophyll b (mg/mL) = 22.9 A645 - 4.68 A663
Carotene = (1000 * A470) - 1.82 Chl a 85.02Chl b)/198

The contents were expressed as mg/g fresh weight, and total chlorophyll was calculated as the sum of Chlorophyll a and Chlorophyll b.

Total Phenolics, Flavonoids Content and Antioxidant Activity: Total Phenolics, Flavonoids Content and Antioxidant Activity was determined by the methods given by Viacava *et al* 2015 with slight modifications (Ahmed et al 2021). The overall flavonoid content was evaluated and represented as milligrams of catechin equivalents (CE) per 100 grams of DW, utilizing a standard curve generated with quercetin.

In order to assess the antioxidant capacity, the DPPH radical assay at 517 nm was utilized, along with the determination of IC50 values measured in micrograms per milliliter of extract, aiming to identify the concentration of the extract needed for a 50% reduction of the DPPH radical. The results obtained were recorded in terms of milligrams of Trolox equivalents (TE) per 100 grams of dry weight (mg TE/100 g DW).

Statistical analysis: All the data was analysed using SPSS and online software WSAP.

Results

Plant morphology and growth characteristics: The present study revealed that all the growth characteristics were recorded higher for hydroponically grown lettuce. A reduction of 26.49% in plant height was recorded in soil grown lettuce in comparison to hydroponically grown lettuce. (Hydro 27.85cm: soil 20.47cm). A great difference was also recorded in root length of both the medium where, root length was 21.52cm for hydroponically grown lettuce and 14.02cm in soil grown lettuce (Fig 2). Similarly, the leaves number in soil grown lettuce was only 19.4 while 32.0 in hydroponically grown lettuce. A significant difference was also recorded for leaf length and width. Hydroponically grown lettuce was having 19.45cm and 11.23cm leaf length and width respectively while soil grown lettuce was having 15.69cm and 8.98cm leaf length and width respectively (Table 1).

Biomass, Moisture and Ash: The fresh weight of shoot was 116.74g and 88.09g for hydroponically and soil grown lettuce respectively while the dry weight of shoot was 8.25g and 5.62g respectively. Whereas, 2.70% decrease in moisture content was recorded in soil grown lettuce. No significant difference was recorded in ash content as the difference was very low. Soil grown lettuce pertained 1.76% ash while hydroponically grown lettuce was having 1.89% ash content (Table 2).

Table 1: Comparison of growth parameters in Soil and Hydroponically grown lettuce.

	Plant height(cm)	Root length(cm)	Number of leaves	Leaf length (cm)	Leaf width (cm)
Soil grown lettuce	20.47±1.025	14.02±0.525	19.4±0.510	15.96±0.69	8.98±0.61
Hydroponically grown lettuce	27.85±0.767	21.52±0.254	32±0.894	19.45±0.82	11.23±0.39

Data based on means of three replicates ± std. error ($n = 10$). ($p<0.01$)

Table 2: Comparison of Biomass, moisture and Ash in Soil and Hydroponically grown lettuce.

	Fresh weight (g)		Dry weight(g)		Moisture content	Ash %
	Shoot	Root	Shoot	Root		
Soil grown lettuce	88.09±2.098	4.90±0.476	5.62±0.531	1.20±0.096	92.65±0.0028	1.76±0.045
Hydroponically grown lettuce	116.74±4.008	28.89±2.003	6.69±0.699	1.55±0.056	94.39±0.0036	1.89±0.068

Table 2: Comparison of Biomass, moisture and Ash in Soil and Hydroponically grown lettuce.

Data based on means of three replicates ± std. error ($n = 10$).

Fig 2. Comparison of Soil and Hydroponically grown lettuce.

Ascorbic acid, Chlorophyll a, b and β-carotene

In the current investigation, it was observed that all nutrients examined exhibited higher levels in lettuce cultivated in soil, with values expressed as milligrams of nutrients per 100 grams (on a fresh weight basis). The mean concentration of ascorbic acid in lettuce grown hydroponically was determined to be 35.29% inferior compared to lettuce grown in soil. Furthermore, levels of chlorophyll a, b, and β-carotene were significantly higher in soil-cultivated lettuce (chl a: soil 26.23 mg/100g, hydro 22.35 mg/100g $p<0.001$; chl b: soil 8.74 mg/100g, hydro 7.45 mg/100g $p<0.001$; *β-carotene* soil 6.99 mg/100g: hydro 5.96 mg/100g $p<0.001$ (Fig.3)

Total phenonics, flavonoids and antioxidant capacity: The total phenolic content of soil grown lettuce (3061.5 GAE/100g DW) was recorded significantly higher than hydroponically grown lettuce (2513.4 GAE/100g DW). Similarly, total flavonoid content was also recorded higher (716.8 mg QE/100g lDW) for soil grown lettuce and lower (530.6 mg QE/100g DW) for hydroponically grown lettuce. The antioxidant activity determined by ABTs was recorded significantly lower (721.6 mg TE/100g DW) in hydroponically grown lettuce as compared to its counterparts (811.9 mg TE/100g DW). On the other hand, IC_{50} value was recorded 2.48 % lower in soil grown lettuce (153.1 µg/ml) (Table 3).

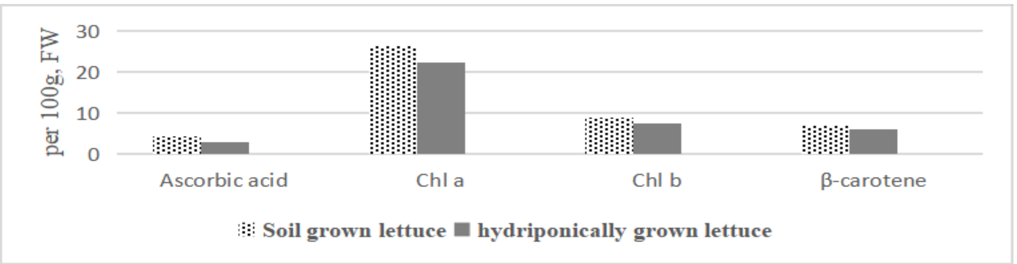

Fig 3. Comparison of Ascorbic acid, Chlorophyll a, b and β-carotene in Soil and Hydroponically grown lettuce.

Table 3: Comparison of phenolics, flavonoids and antioxidants capacity in soil and hydroponically grown lettuce.

	Soil grown Lettuce	**Hydroponically grown Lettuce**
Total phenolics	3061.5±60.59	2513.4±43.6
Total flavonoids	716.8±41.9	530±25.4
ABTS (mg/100g)	811.9±10.1	721.6±12.6
IC50 (µg/ml)	153.1±1.8*	157.0±2.1*

*Values are the mean (n = 10) ± SE. Means with * are significantly different at $p \leq 0.05$ using the LSD test.*

Discussion

Hydroponically grown lettuce typically exhibits a faster growth rate compared to soil-grown lettuce due to several factors inherent in hydroponic systems. One of the primary reasons is the immediate availability of nutrients. This straightforward nutrient delivery system removes the necessity for plants to use energy in retrieving nutrients from the soil, which can fluctuate in both nutrient composition and accessibility. Numerous studies have demonstrated that hydroponic systems can significantly enhance the growth rate and yield of lettuce compared to traditional soil cultivation. For instance, Resh (2013) reported that hydroponically grown lettuce exhibited a faster growth rate and higher yield due to the direct and consistent access to nutrients. Atieno et al (2020) suggests that soil health and fertility are critical for the successful growth of soil-grown crops, and any deficiencies or imbalances in soil nutrients can significantly impact plant growth. Research by Jensen (1997) also supports this observation, indicating that hydroponically grown lettuce can mature in as little as half the time it takes for soil-grown lettuce.

In the present study biomass and moisture was also recorded higher for hydroponically grown lettuce whereas very little difference was recorded in ash %. The vegetative growth of the plant, as well as its fresh biomass (Table 2), is closely linked with the food stores present in its leaves, shoots, or roots. The ability of the plant to hold water and its aeration, turn ensures an increase in the photosynthetic potential of the leaves. The water retention capacity, gaseous exchange, and root penetration of a medium are contingent upon the quantity of pore space available, thereby contributing to better plant growth (Burnett et al 2016; Sakoda et al 2020). A study by Nicole et al. (2016) found that hydroponically grown lettuce produced up to 50% more biomass compared to soil-grown lettuce. A study by Savvas and Gruda (2018) demonstrated that hydroponic systems could produce up to 30-40% higher yields of leafy greens, including lettuce, compared to conventional soil-based agriculture. Furthermore, research by Saha et al (2016) showed that the yield of hydroponically grown lettuce was consistently higher across different hydroponic methods, including nutrient film technique (NFT) and deep-water culture (DWC), compared to traditional soil cultivation.

These findings suggest that hydroponic systems provide a more reliable and productive method for growing lettuce, particularly in regions with poor soil quality or limited arable land.

The level of moisture present in plants is a vital determinant that significantly affects the longevity and palatability of newly harvested vegetables. It may also have a significant impact on the safety of food consumption (Kyere et al 2020). In our study we recorded that hydroponically grown lettuce had 2.70 % more moisture content than soil grown lettuce (Table-2) This study also supported by Fallowo et al (2009), Perez-lopez et al (2016), Harris (2015), Touliatos et al (2016). Despite this, Fontana et al (2018), Manzocco et al (2011), and Siomos et al (2001) have reported a lower dry matter content in hydroponically grown lettuce. Barg et al (2009) conducted an observation wherein it was discerned that lettuce leaves with elevated moisture content underwent increased weight loss during storage and were found to be more susceptible to spoilage. According to the research conducted by Ares et al (2008), it was found that a product with a short shelf life was associated with a higher consumer rejection.

On the other hand, the study revealed the highest levels of total phenolics, flavonoids, and antioxidant activity in soil grown lettuce (Table 3). Lanzi et al. (2004) made a discovery during their study which revealed that organic tomatoes exhibited higher levels of flavanols, vitamin C, and vitamin E, based on fresh weight measurements. However, after being recalculated based on dry weight measurements, the significance of these findings decreased, a phenomenon that can be attributed to the higher water content found in conventionally cultivated tomatoes (Caris-Veyrat et al 2004, Chassy et al 2006).

Crucial bioactive phytochemicals like ascorbic acid, chlorophylls, β-carotene, and total phenolics are essential for maintaining human health. Frezza et al. (2005) noted a significant difference in ascorbic acid content, observing a 72% decrease in hydroponically grown lettuce compared to soil-grown lettuce in a greenhouse environment. This reduction was linked to the higher nitrogen levels present in the hydroponic system, which can promote increased foliage growth, subsequently reducing light exposure and ascorbic acid accumulation. A similar theory regarding the impact of nitrogen on ascorbic acid levels in plants was put forth by Lee and Kader (2000). Typically, the concentration of ascorbic acid in fresh vegetables such as lettuce is low and notably unstable. Albrecht (1993) documented a retention rate ranging from 40 to 74% for ascorbic acid in lettuce preserved for a week. Siomos et al (2001) presented similar results suggesting that lettuce from hydroponic systems displayed lower levels of chlorophyll a, b, and total chlorophyll compared to those from conventional soil cultivation methods. A recent investigation by Zapata-Vahos et al (2020) revealed significantly higher total phenolic content in soil-cultivated red lettuce compared to hydroponically grown red lettuce, supporting the current study's results. The increased presence of phenolic compounds, flavonoids, chlorophyll, and carotenoids in the plant primarily corresponded with antioxidant characteristics, consistent with our own results (Nicolle et al 2004). Hydroponically grown lettuce is also more scalable, economically feasible, and environmentally sustainable than soil-grown lettuce due to its efficient resource utilization and adaptability. By supporting vertical farming, hydroponics maximizes space use and enables year-round production, making it ideal for urban areas with limited arable land. The precise control of water and nutrients significantly reduces waste and minimizes the need for fertilizers and pesticides, cutting operational costs and environmental impact. Additionally, hydroponic systems often deliver higher yields in shorter growth cycles, ensuring quicker returns on investment despite higher initial setup costs. Their ability to thrive in controlled environments also eliminates reliance on soil quality and seasonal conditions, offering a consistent and sustainable production model. The environmental and cost implications of hydroponic systems compared to soil cultivation highlight both opportunities and challenges that deserve closer examination. Environmentally, hydroponics offers significant advantages, including reduced water use—up to 90% less than traditional soil cultivation—elimination of soil erosion, and prevention of nutrient runoff. However, it relies heavily on synthetic nutrient solutions and energy for lighting, heating, and pumps, which can increase its carbon footprint, particularly in regions where renewable energy is not utilized. From a cost perspective, hydroponic systems require a substantial initial investment for setup, including infrastructure, automation, and maintenance, making them less accessible for small-scale farmers. In contrast, soil cultivation typically has lower startup costs but involves ongoing expenses like fertilizers, pest management, and irrigation. Understanding these trade-offs is critical for optimizing the sustainability and affordability of hydroponics, particularly as global agriculture faces increasing pressure to reduce environmental impacts while meeting rising food demands.

Conclusion

In this comparative study between hydroponically grown and soil-grown lettuce, we observed distinct outcomes across growth parameters and biochemical activities. Our findings suggest that while hydroponic cultivation excels in optimizing growth efficiency, traditional soil-based methods may offer advantages in enhancing biochemical constituents crucial for nutritional quality and functional benefits. The choice between these cultivation methods should be considered based on specific goals, such as maximizing yield versus enhancing nutritional value, thereby informing sustainable agricultural practices and dietary strategies. Both methods offer distinct advantages, highlighting the importance of aligning cultivation practices with targeted agricultural and dietary objectives.

Conflict of interest The authors have no relevant financial or non-financial interests to disclose.

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