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Unlocking Parsley's Nutritional Potential: A Comparative Study Of Hydroponic And Soil-Based Cultivation Systems Across Diverse Genotypes

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ABSTRACT

Hydroponic farming systems have gained attention for their potential to enhance crop nutritional quality and yield. The present study investigates the nutritional composition of seven parsley genotypes cultivated under hydroponic NFT (Nutrient Film Technique) and polyhouse conditions. The experimentation was designed in randomized block design (RBD). Our results shows that hydroponic NFT system significantly improves the nutritional parameters of parsley, including protein content (up to 14.50% in genotype Giant Plain), iron content (ranging from 794.80 to 1541.80 mg/kg), and vitamin C levels (up to 1676.21 mg/kg in genotype Giant Plain), compared to polyhouse conditions. The minerals content i.e., iron in genotype Gigante Italian (1541.80±2.59 mg/kg) and calcium content in Forest Green (3.62±0.32 %) was highest under hydroponic farming system. The hydroponic NFT system produces higher protein content, iron content, and vitamin C levels, making it a promising approach for addressing micronutrient deficiencies. The improved nutritional quality in NFT system may be attributed to optimized nutrient delivery and uptake. FTIR spectroscopy analysis reveals the presence of different functional groups such as C-H stretching, C=C stretching, alkanes, alkenes and aromatic compounds in different genotypes and farming systems. Overall, this study highlights the potential of NFT farming system for producing nutrient-rich parsley, with implications for improving food security and nutritional quality.

Keywords: *FTIR; hydroponic; nutritional quality; parsley and soil-based farming*

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1. INTRODUCTION

The world's population is extended to outreach 9.7 billion by 2050, putting huge pressure on agri-food systems. With 50% of arable land expected to become unusable due to degradation and erosion (Kumar et al., 2022). To meet the enlarging demand, food production needs to be expanded by one hundred ten percent. In accordance with the United Nations, many countries are facing a food crisis that may persist until 2050 if demands are not met (Cramer, 2002; McKenzie and Williams, 2015). Climate change, characterized by frequent droughts and floods, is a major contributor to this crisis. Additionally, poverty, soil erosion, and degradation due to conventional farming methods exacerbate the issue. In this context, innovative techniques like hydroponics can play a vital role in improving and increasing crop productivity.

Hydroponics, a method of growing crops without soil, is increasing popularity globally because of its potential to enhance ecological sustainability (Jensen, 1999; Rajaseger et al., 2023). By allowing crop cultivation in urban or dry areas, nevertheless of soil aspects, hydroponics (soilless) enables food production connected to consumers, reducing transportation costs and increasing freshness (Bellows et al., 2003). In India, where the population is growing rapidly, hydroponics is being adopted on a large scale to address food security challenges. With its numerous benefits, hydroponics offers a promising solution to ensure sustainable food producing and meet the demands of an increasing population (Rajaseger et al., 2023).

Parsley (*Petroselinum crispum*) is a prominent herb used in food and cosmetics for its medicinal properties (Agyare et al., 2017). It is dark green, leafy plant rich in vitamins, minerals, and antioxidants (Bahramsoltani et al., 2024). Parsley is widely used in cooking and has been a part of culinary traditions for centuries. There are three major kinds of parsley: plain leaf parsley (*Petroselinum crispum* var. *neapolitanum*), curled leaves parsley (*Petroselinum crispum var. crispum*), and turnip or "Hamburg" rooted parsley (*Petroselinum crispum* var. *tuberosum*) (Ellis et al., 1974). Due to its high nutritional value, parsley is considered a 'powerhouse' of nutrients. It's a quality source of vitamins B and C, potassium, and zinc. Parsley also contains essential minerals like boron and fluorine, which support bone and muscle health (Dobricevic et al., 2019; Staropoli et al., 2021). Additionally, parsley has been found to have diverse health advantages, including antioxidant and anti-inflammatory activities (Farzaei et al., 2013). A study conducted by Indira and Rani (2024) on *Ocimum basilicum* found that hydroponic systems showed higher nitrogen concentration compared to soil-grown plants, supporting the potential benefits of hydroponics.

In the present study, we hypothesized that parsley grown under hydroponic conditions will exhibit enhanced nutritional quality and productivity compared to traditional soil-based farming systems. However, in this context, no investigation has been done on the nutritional potential of parsley grown under different cultivation systems. So, the focus of this research was to compare the nutritional ability of parsley grown under hydroponic (soilless)and soil-based farming systems, also identify the most effective cultivation method for enhancing its nutritional value and productivity.

2. MATERIALS AND METHODS

2.1. Collection and establishment of parsley genotypes

Seven different seeds of parsley genotype were collected from diverse sources. The study was performed at the experimental farm of CSKHPKV Palampur 32° 6' N latitude, and 76° 3' E longitude (1290.8 m above mean sea level) from September 2022 to February 2023, during the spring-summer season. Seeds were sown in a high-tech nursery production unit using a growing medium consisting of cocopeat, vermiculite, and perlite in a 3:1:1 ratio in plug trays.

2.2. Experimental design

The experiment comprises of two treatments: (1) Hydroponic installation using the Nutrient Film Technique (NFT) and (2) Polyhouse condition with acidic soil (pH 5.7). A completely randomized block design (RBD) was employed having thirteen biological replicates for each treatment, and replicate consisted of seven genotypes. Seedlings with 3-4 true leaves were transplanted into hydroponic net channels (NFT) and polyhouse condition. Irrigation was initiated immediately after transplanting, with twice a week. For hydroponics, Hoagland nutrient solution was used as the primary source of nutrients. For further analysis shade-dried plant samples was used.

2.3. Nutrient analysis

2.3.1. Moisture content

Moisture content of the sample was described the method followed by Unuofin et al. (2017). For this, an empty petri plate was oven-dried for an hour at 105°C, cool it, and then weighed (W1). Approximately 3 g of the powdered sample was accurately weighed and placed in the pre-weighed oven-dried petri plate (W2). The sample were heated at 105°C in a hot air oven till the weight remained constant. The sample was then cool down in a desiccator and re-weighed (W3). Moisture content was calculated and expressed as a percentage.

$$\text{Moisture (\%)} = \frac{\text{W2} - \text{W3}}{\text{W2} - \text{W1}} \times 100$$

2.3.2. Ash content

The ash composition of the sample was determined reported the method followed by Unuofin et al. (2017). A crucible was dried at 105°C for 1 hour, cooled, and then weighed (W1). Around 3 g of powdered sample was accurately weighed and placed an empty crucible that has been pre-weighed. The initial weight of the sample with crucible was noted (W2). The sample in the crucibles were heated in a muffle furnace at 250°C for 1 hour followed by 550°C for 5 hours. After cooling, the crucibles were re-weighed (W3). The ash content was calculated as a percentage.

$$\text{Ash content (\%)} = \frac{W2 - W3}{W2 - W1} \times 100$$

2.3.3. Crude Fat content

The fat content of the sample was determined using Soxhlet extraction, as described by AOAC (2005). 5 g of powdered sample was precisely measured and inserted into an extraction thimble, which was then placed into the Soxhlet extractor attached to a boiling flask filled with solvent that is petroleum ether. The initial weight of the boiling flask (W1) was recorded. The extraction was carried out for 4-6 hours at a temp. range of 60-68°C. Following extraction, the petroleum ether was evaporated, and the residue was oven-dried to obtain the extracted fat. The weight of the boiling flask with the extracted fat (W2) was then recorded, and the fat content was calculated:

$$\text{Crude fat (\%)} = \frac{W2 - W1}{\text{Weight of orginal sample}} \times 100$$

2.3.4. Crude fibre content

The crude fibre of the sample was described according to the method followed by Unuofin et al. (2017) with slight changing. 3 g of powdered sample was treated with 150 ml of sulphuric acid (H_2SO_4, 1.25%) in a conical flask, which was later boiled for 30 minutes on a hot plate. The mixture was filtered by using muslin cloth and rinsed with warm water to eliminate acid residue. The residues were then boiled with 150 ml of sodium hydroxide (NaOH ,1.25%) for 30 minutes, again by filtration and wash with warm water. The remaining residue was oven-dried at 110°C for 2 hours and weighed (CF1). Subsequently, the residue was inflamed in a muffle furnace at 550°C for 4 hours to acquire greyish ash, and reweighed (CF2). The percentage of crude fibre was calculated based on the weights obtained.

$$\text{Crude fibre (\%)} = \frac{CF2 - CF1}{\text{Weight of orginal sample}} \times 100$$

2.3.5. Crude protein content

The Kjeldahl method (OAC, 1990) was utilized to measure the crude protein in the sample, using which involved protein digestion and distillation. Briefly, 1 g of powdered sample was digested with concentrated H_2SO_4 (20 ml) and 5 g of digestion mixture in a Kjeldahl flask until a transparent residue was obtained. After cooling, the digest was diluted to 100 ml with distilled water. For distillation, 5 ml of the digest was treated with NaOH (10 ml of 40%) in a micro-Kjeldahl apparatus, and the distillate was accumulated in H_3Bo_3 (10 ml of 4%). The distillate was then titrated against H_2SO_4 (0.02 N), in the end show by a colour change from dark blue to wine-red.

$$\text{Nitrogen (\%)} = \frac{0.00028 \times (S - B) \times 100}{W \times 5} \times 100$$

where S is the amount of acid used for titration, B is the amount of acid used for blank and W is the weight of the sample.

$$\text{Crude protein content (\%)} = \text{Nitrogen (\%)} \times F$$

where F is the conversion factor equivalent to 6.25.

2.3.6. Total carbohydrate content

The total carbohydrate percentages were determined using the following formula given by James (2013):

$$\%\ \text{Carbohydrate} = 100 - (\%\ \text{Moisture} + \%\ \text{Ash} + \%\ \text{Fat} + \%\ \text{Crude fiber} + \%\ \text{Crude protein})$$

2.3.7. Food energy

The food energy content was calculated using the formula of Verma and Srivasta (2017) as described:

$$\text{Food Energy}\left(\frac{\text{kJ}}{100\text{g}}\right) = (4 \times \%\ \text{Crude Protein}) + (9 \times \%\ \text{Fat}) + (4 \times \%\ \text{Carbohydrate})$$

2.4. Mineral analysis

The minerals were estimated in the parsley samples using atomic absorption spectroscopy. Preparation of samples was done using the diacid mixture method (Renuka et al., 2016). Briefly, perchloric and nitric acid were mixed in a 9:4 ratio to prepare the reagent. 1 g of the sample was then weighed and placed in a digestion flask, in which 15 ml of the prepared acid reagent was added. The sample was digested by heating until it was fully dissolved and left overnight. Then, the mixture was gradually heated to 60°C, ensuring careful control to avoid overheating. Heating continued until only a white residue was left in the flask. The white residue was then mixed with 25 ml of purified water, which was add on dropwise with continual stirring to dissolve the minerals. After cooling, the total volume was made up to 100 ml and then the solution was filtered using the Whatman filter paper. All readings were made in triplicates using an atomic absorption

spectrophotometer. Total phosphorous was determined colorimetrically at 470 nm using KH_2PO_4 as a standard.

2.5 UHPLC (Ultra-High-Performance Liquid Chromatography)

Vitamin analysis was performed using a Thermo Fisher Scientific Dionex Ultimate 3000 UHPLC system (Thermo Fisher Scientific, USA) at the Food Testing Lab, Shoolini University, Solan, H.P (Himachal Pradesh). The system consisted of quaternary pump, vacuum degasser, autosampler with thermostat, photodiode array detector (DAD) and column compartment thermostat, The system was coupled with Zorbax Eclipse C18 column (4.6 mm × 250 mm, 5 µm) (Agilent Technologies, USA). UHPLC separated vitamins based on polarity, with water-soluble vitamins analyzed under reversed-phase conditions and fat-soluble vitamins typically requiring supercritical fluid chromatography (SFC) conditions (Rathi et al., 2019). For water-soluble vitamins, the mobile phase comprised 0.1% formic acid and methanol (90:10, v/v) at a flow rate of 0.6 mL/min. The column temperature was upholding at 30°C, and detection was performed at 254 nm. For fat-soluble vitamins, the mobile phase comprises of methanol and water (98:2, v/v) with a gradient flow rate: 1 mL/min (0-5 min), 1.2 mL/min (5-5.5 min), and 1.2 mL/min (5.5-20 min). The temperature of column was 30°C, and detection wavelengths were 265 nm and 284 nm.

2.6. FTIR (Fourier Transform Infrared Spectroscopy) profiling

FTIR spectroscopy was conducted on powder sample derived from leaves and stem of various *P. crispum* genotypes using an IR Bruker alpha spectrometer (Serial No. 200808). A small amount of sample was put on the FTIR sample holder under constant pressure. The FTIR spectra, obtained in the range of 500-4000 cm^{-1}, were used to recognized functional groups of phytochemicals by measuring infrared absorption, emission, and photoconductivity spectra, based on the method of Dhalaria et al. (2024).

2.7. Statistical analysis

All measurements were performed in three repetitions, and results are showed as mean values ± standard error of the mean (SEM). Statistical significance was calculated using analysis of variance (ANOVA) with SPSS (Statistical package for the Social Science) software, followed by Duncan's Multiple Range Test, with p-values < 0.05 considered significant.

3. RESULTS

3.1. Proximate composition

The proximate composition of parsley genotypes grown under polyhouse conditions is presented in Table 1. The moisture content ranged from 11.66 ± 0.02% to 12.66 ± 0.20%, with non-significant differences among genotypes. However, significant variations were observed in other proximate components. Ash content was found to be highest (13.00 ± 0.40%) in Krausa Curled genotype and lowest (8.60 ± 0.20%) in Giant Plain. The Giant Plain genotype also had the lowest (1.80 ± 0.20%) total fat content. Crude fibre content was found highest (5.62 ± 0.10%) in Triple Curled genotype. All genotypes had appreciable protein content (>12%). Giant Plain and Moss Curled had the highest (58.70%) total carbohydrate content, while Cress Curled had the lowest (54.41%) carbohydrate content. The total energy content was observed to be highest (307.40 ± 0.40 kcal/100g) in Moss Curled and lowest (291.80 ± 2.20 kcal/100g) in Cress Curled genotype. Except for moisture content, all proximate components showed significant differences among genotypes.

The proximate composition of parsley genotypes grown under hydroponic NFT farming system, showed significant variations among genotypes (Table 2). Moisture content ranged from 12.33 ± 0.47% to 13.43 ± 0.24%, with Gigante Italian exhibiting the highest (13.43 ± 0.24%) and Moss Curled exhibiting the lowest (12.33 ± 0.47%) content. The ash content varied significantly, with Krausa Curled having the lowest (9.00 ± 0.40%) and Triple Curled having the highest (12.13 ± 0.40%) content. The fat content was observed lowest (1.33 ± 0.02%) in Forest Green and highest in Triple Curled (1.50 ± 0.04%) parsley genotype. The crude fibre content was found highest (5.80 ± 0.04%) in Moss Curled and lowest (5.23 ± 0.09%) in Cress Curled genotype. All genotypes had appreciable protein content (>13%), with significant differences among them. The total carbohydrate content ranged from 54.26 ± 0.29% to 58.77 ± 0.72%, with all genotypes exceeding 50%. The energy content was found significantly highest in Moss Curled (302.32 ± 1.17 kcal/100g) and lowest in Triple Curled (284.43 ± 1.12 kcal/100g) genotype.

Table 1. Proximate composition of parsley genotypes under polyhouse conditions.

Genotypes	Moisture (%)	Ash (%)	Crude fat (%)	Crude fibre (%)	Crude protein (%)	Total carbohydrate (%)	Total energy (kcal/100g)
Triple Curled	12.30 ± 0.20^{a}	9.30 ± 0.20^{a}	2.00±0.07^{b}	5.62±0.10^{d}	12.30±0.10^{a}	58.30±0.50^{e}	301.00±1.30^{b,c}
Gigante Italian	12.66± 0.20^{a}	10.60± 0.20^{b}	2.20±0.02^{d}	5.50±0.04^{b,c,d}	13.41±0.20^{b}	55.51±0.60^{a,b}	296.02±2.01^{a,b}
Cress Curled	12.33± 0.20^{a}	12.31 ±0.20^{e}	2.19±0.07^{c,d}	5.11±0.09^{b}	13.41±0.10^{b}	54.41±0.50^{a}	291.80±2.20^{a}
Giant Plain	12.00± 0.40^{a}	8.60 ± 0.20^{a}	1.80±0.02^{a}	5.10±0.07^{b}	13.61±0.10^{b}	58.70±0.50^{e}	306.00±1.90^{e}
Moss Curled	11.70 ± 0.20^{a}	9.32 ± 0.20^{a}	2.00±0.02^{b,c}	4.70±0.08^{a}	13.40±0.10^{b}	58.70±0.10^{e}	307.40±0.40^{e}
Krausa Curled	12.00 ± 0.40^{a}	13.00 ±0.40^{e}	2.10±0.02^{b,c,d}	4.70±0.09^{a}	12.50±0.10^{a,b}	55.60± 0.30^{a,b}	293.06±2.30^{a}
Forest Green	11.66± 0.02^{a}	9.80 ± 0.30^{a,b}	2.03±0.02^{b}	5.30±0.05^{c,d}	13.20±0.09^{b}	57.61±0.50^{b,c}	301.92±2.31^{b,c}

Notes: Means with a similar uppercase letter in the same column are not significantly different; p value by permutation ($p < 0.05$).

Table 2. Proximate composition of parsley genotypes under Nutrient Film Technique farming system.

Genotypes	Moisture (%)	Ash (%)	Crude fat (%)	Crude fibre (%)	Crude protein (%)	Total carbohydrate (%)	Total energy (kcal/100g)
Triple Curled	13.00±0.47^{a}	12.13±0.40^{e}	1.50±0.04^{a}	5.63±0.10^{a,b}	13.08±0.47^{a}	54.73±0.87^{a}	284.43±1.12^{a}
Gigante Italian	13.43±0.24^{b}	10.83±0.30^{b,c}	1.46±0.07^{a}	5.63±0.09^{a,b}	13.68±0.01^{b}	55.08±0.68^{a}	288.26±2.19^{b}
Cress Curled	12.66±0.47^{a}	9.93±0.041^{a,b}	1.36±0.02^{a}	5.23±0.09^{a}	13.63±0.28^{b}	57.27±0.60^{b}	295.76±1.65^{c}
Giant Plain	13.00±0.81^{a}	11.66±0.21^{e}	1.43±0.02^{a}	5.63±0.02^{a,b}	14.50±0.09^{c}	54.26±0.29^{a}	287.96±1.08^{b}
Moss Curled	12.33±0.47^{a}	9.17±0.23^{a}	1.43±0.02^{a}	5.80±0.04^{b}	13.59±0.15^{b}	58.76±0.45^{e}	302.32±1.17^{d}
Krausa Curled	12.71±0.41^{a}	9.00±0.40^{a}	1.40±0.04^{a}	5.43±0.22^{a}	13.41±0.05^{b}	58.77±0.72^{e}	301.36±2.83^{d}
Forest Green	12.66±0.22^{a}	9.33±0.42^{a,b}	1.33±0.02^{a}	5.60±0.04^{a,b}	13.41±0.08^{b}	57.38±0.26^{b}	295.23±0.95^{c}

Notes: Means with a similar uppercase letter in the same column are not significantly different; p value by permutation ($p < 0.05$).

3.2. Mineral analysis

The mineral composition of parsley genotypes grown under polyhouse conditions is presented in Table 3. Significant differences were observed in the concentrations of P, K, Fe, Na, S, Mn, Zn and Cu among the seven genotypes. The highest (0.19 ±0.01%) P content was observed in Cress Curled genotype, while the lowest (0.15 ± 0.04% and 0.15 ± 0.01%) content was observed in Moss Curled and Triple Curled genotype respectively. The K content was found highest (2.66 ± 0.39%) in Triple Curled and the lowest (1.80 ± 0.37%) in Giant Plain genotype. The Forest Green genotype showed the highest (3.04 ± 0.46%) Ca content, while the Moss Curled showed the lowest (2.61 ± 0.08%) content. The Fe and Mn content was found highest (529.95 ± 0.53 mg/kg and 11.55 ± 0.41 mg/kg respectively) in Moss Curled genotype and the lowest (210.10 ± 0.51 mg/kg) Fe and (8.00 ± 0.36 mg/kg) Mn was observed in Forest Green and Cress Curled genotype respectively. The Giant Plain genotype showed the highest (108.85 ± 0.57 mg/kg) Zn content, and Kruasa Curled showed the lowest (69.90 ± 0.93 mg/kg) content. The highest (14.85 ± 0.49 mg/kg) Cu content was observed in Triple Curled genotype while the Moss Curled observed the lowest (5.80 ± 0.46 mg/kg) content.

In the hydroponic NFT farming system, the concentrations of minerals Ca, Na showed non-significant variations, while the significant variations were observed in P, K, Fe, S, Mn, Zn, and Cu concentrations among the different genotypes showed in table 4. The Cress Curled genotype showed the highest (0.19 ± 0.02%) P content, while Triple Curled and Krausa Curled showed the lowest (0.16 ± 0.01% and 0.16 ± 0.04%) P content. The K content was highest (4.42 ± 0.47%) in Triple Curled and the lowest (2.60 ± 0.43%) in Giant Plain genotype. The highest (0.08 ± 0.01% and 3.62 ± 0.32%) S and Ca content respectively was observed in the Forest Green genotype while Krausa Curled showed the lowest (0.03 ± 0.01%) S content and Moss Curled showed the lowest (3.01 ± 0.34%) Ca content. The Na content was highest (0.55 ± 0.22%) in Giant Plain and lowest (0.32 ± 0.05%) in Krausa Curled. The Fe and Zn content was found highest (1541.80 ± 2.59 mg/kg and 144.15 ± 1.51 mg/kg respectively) in Gigante Italian, while Giant Plain showed the lowest (794.80 ± 12.49 mg/kg) Fe content, and Krausa Curled showed the lowest (81.55 ± 0.40 mg/kg) Zn content. The Triple Curled genotype showed the highest (19.05 ±0.47 mg/kg) Cu content, while Giant Plain showed the lowest (3.50 ± 0.16 mg/kg) Cu content.

Table 3. Mineral content of parsley genotypes under polyhouse conditions.

Genotypes	P (%)	K (%)	S (%)	Ca (%)	Na (%)	Fe (mg/kg)	Mn (mg/kg)	Zn (mg/kg)	Cu (mg/kg)
Triple Curled	0.15±0.01^{a}	2.66±0.39^{a}	0.04±0.01^{a}	2.73±0.14^{a}	1.32±0.24^{b}	212.40±0.46^{a}	8.95±0.47^{a}	81.70±0.59^{c}	14.85±0.49^{c}
Gigante Italian	0.16±0.02^{a}	2.02±0.46^{a}	0.18±0.08^{c}	2.99±0.07^{a}	1.39±0.47^{b}	251.85±0.47^{b}	9.10±0.44^{a}	70.60±0.45^{a}	9.75±0.52^{b}
Cress Curled	0.19±0.01^{b}	1.90±0.01^{a}	0.04±0.01^{a}	3.02±0.45^{a}	0.67±0.04^{a}	345.10±0.47^{c}	8.00±0.36^{a}	73.90±0.02^{b}	9.65±0.53^{b}
Giant Plain	0.16±0.04^{a}	1.80±0.37^{a}	0.06±0.09^{a,b}	2.91±0.11^{a}	1.24±0.24^{b}	374.90±0.78^{d}	10.75±0.47^{b,c}	108.85±0.57^{d}	14.20±0.38^{c}
Moss Curled	0.15±0.04^{a}	1.93±0.32^{a}	0.07±0.02^{a,b}	2.61±0.08^{a}	1.32±0.19^{b}	529.95±0.53^{e}	11.55±0.41^{c}	73.75±0.43^{b}	5.80±0.46^{a}
Kruasa Curled	0.17±0.02^{a,b}	1.81±0.38^{a}	0.08±0.01^{a,b}	2.87±0.16^{a}	0.94±0.07^{b}	247.95±4.71^{b}	8.90±0.49^{a}	69.90±0.93^{a}	6.60±0.25^{a}
Forest Green	0.17±0.04^{a,b}	2.41±0.25^{a}	0.09±0.01^{b}	3.04±0.46^{a}	0.92±0.01^{b}	210.10±0.51^{a}	9.50±0.11^{a,b}	71.60±0.46^{a}	9.55±0.09^{b}

Notes: Means with a similar uppercase letter in the same column are not significantly different; p value by permutation ($p < 0.05$).

Table 4. Mineral content of parsley genotypes under Nutrient Film Technique farming system.

Genotypes	P (%)	K (%)	S (%)	Ca (%)	Na (%)	Fe (mg/kg)	Mn (mg/kg)	Zn (mg/kg)	Cu (mg/kg)
Triple Curled	0.16±0.01^{a}	4.42±0.47^{b}	0.04±0.01^{a}	3.34±0.39^{a}	0.36±0.08^{a}	1317.60± 13.88^{d}	22.15±0.51^{d}	118.95±0.27^{d}	19.05±0.47^{e}
Gigante Italian	0.18±0.01$^{a, b}$	3.90±0.47$^{a, b}$	0.05±0.01$^{a, b}$	3.51±0.35^{a}	0.46±0.06^{a}	1541.80±2.59^{e}	29.90±0.59^{e}	144.15±1.51^{e}	4.50±0.24^{a}
Cress Curled	0.19±0.02^{b}	4.24±0.11^{b}	0.07±0.01$^{a, b}$	3.45±0.29^{a}	0.34±0.07^{a}	1018.75±7.15^{b}	19.95±0.44^{c}	105.75±0.71^{c}	7.60±0.55^{b}
Giant Plain	0.17±0.01^{a}	2.60±0.43^{a}	0.05±0.01$^{a, b}$	3.32±0.32^{a}	0.55±0.02^{a}	794.80±12.49^{a}	21.40±0.25$^{c, d}$	123.70±0.43^{d}	3.50±0.16^{a}
Moss Curled	0.17±0.02^{a}	3.39±0.11$^{a, b}$	0.06±0.01$^{a, b}$	3.01±0.34^{a}	0.51±0.02^{a}	1481.40±9.44^{e}	16.35±0.29^{b}	90.30±3.18^{b}	7.70±0.53^{b}
Kruasa Curled	0.16±0.04^{a}	3.33±0.19$^{a, b}$	0.03±0.01^{a}	3.17±0.27^{a}	0.32±0.05^{a}	1132.60±9.44^{c}	13.55±0.26^{a}	81.55±0.40^{a}	4.90±0.04^{a}
Forest Green	0.17±0.01^{a}	3.42±0.14$^{a, b}$	0.08±0.01^{b}	3.62±0.32^{a}	0.37±0.06^{a}	1312.60±4.81^{d}	12.60±0.44^{a}	93.15±2.23^{b}	7.25±0.46^{b}

Notes: Means with a similar uppercase letter in the same column are not significantly different; p value by permutation ($p < 0.05$).

3.3. Vitamins

The results revealed significant differences in vitamin A, E, K, and C content among parsley genotypes and different farming systems. In the polyhouse condition, vitamin A content varied significantly from 0.15 ± 0.01 mg/kg to 39.18 ± 4.18 mg/kg, with Krausa Curled having the highest content and Cress Curled having the lowest content. The vitamin E content ranged from 0.10 ± 0.02 mg/kg to 10.61 ± 0.50 mg/kg, with the highest content observed in Krausa Curled and the lowest observed in genotype Gigante Italian. The vitamin K content in parsley genotype ranged from 0.15 ± 0.01 mg/kg to 2.78 ± 0.09 mg/kg, with the greatest content found in Krausa Curled and the lowest content found in Gigante Italian genotype. The vitamin C content showed the most significant variation, ranging from 4.46 ± 0.05 mg/kg to 451.61 ± 8.69 mg/kg, with Krausa Curled the highest content and Cress Curled having the lowest vitamin C content showed in table 5.

In the NFT farming system, significant variations were observed in vitamin content. Vitamin A ranged from 0.02 ± 0.08 mg/kg to 29.54 ± 1.89 mg/kg, with Triple Curled genotype exhibiting the highest content and Moss Curled showing the lowest vitamin A content. Vitamin E content varied significantly from 0.23 ± 0.01 mg/kg to 6.93 ± 0.53 mg/kg, with the highest content observed in Giant Plain and the lowest in Gigante Italian genotype. Vitamin K content ranged from 0.15 ± 0.01 mg/kg to 6.57 ± 0.07 mg/kg, with Moss Curled showing the highest content and Giant Plain showing the lowest content. Most significant variation was observed in vitamin C content, ranging from 26.52 ± 0.80 mg/kg to 2639.17 ± 11.55 mg/kg, with Krausa Curled having the highest content and Cress Curled having the lowest content. Furthermore, the data revealed that hydroponic farming systems generally promoted higher vitamin C content in most genotypes and hydroponic NFT farming system, Giant Plain genotype exhibited the highest vitamin C content (Table 5).

Table 5. Vitamin content of parsley genotypes under polyhouse condition and Nutrient Film Technique farming system.

	Poly house condition				NFT system			
Vitamin (mg/kg) / Genotypes	Vitamin A	Vitamin E	Vitamin K	Vitamin C	Vitamin A	Vitamin E	Vitamin K	Vitamin C
Triple Curled	1.05±0.02^{a}	0.30 ±0.04^{a}	0.17±0.01^{a}	58.76±3.65^{b}	29.54 ±1.89^{e}	0.51 ±0.04^{a}	0.22 ±0.04^{a}	948.62 ±7.72^{b}
Gigante Italian	6.13±0.40^{a}	0.10±0.02^{a}	0.15±0.01^{a}	68.70±3.49^{b}	4.05 ±0.13^{b}	0.23 ±0.01^{a}	1.18 ±0.08^{c}	1288.40 ± 8.43^{c}
Cress Curled	0.15±0.01^{a}	0.69±0.07$^{a, b}$	0.42±0.02^{b}	4.46 ±0.05^{a}	0.48 ±0.04^{a}	3.33 ±0.06^{b}	0.30 ±0.04$^{a, b}$	26.52 ±0.80^{a}
Giant Plain	15.37±0.90^{b}	0.40 ±0.02^{a}	2.05±0.07^{c}	59.48±3.17^{b}	9.50 ±0.54^{c}	6.93 ±0.53^{c}	0.15 ±0.01^{a}	1676.21 ±5.39^{e}
Moss Curled	0.85±0.05^{a}	1.12±0.04^{b}	0.27±0.02$^{a, b}$	59.91±3.52^{b}	0.02 ±0.08^{a}	0.40 ±0.05^{a}	6.57 ±0.07^{d}	1525.56 ±2.39^{d}
Kruasa Curled	39.18±4.18^{e}	10.61±0.50^{e}	2.78±0.09^{d}	451.61±8.69^{d}	14.63 ±0.94^{d}	0.50 ±0.03^{a}	0.16 ±0.02^{a}	2639.17±11.55^{f}
Forest Green	3.42±0.15^{a}	0.30 ±0.02^{a}	0.20±0.04^{a}	148.20±0.50^{c}	4.89 ±0.47^{b}	0.50 ±0.04^{a}	0.50 ±0.11^{b}	1571.46 ±2.67^{d}

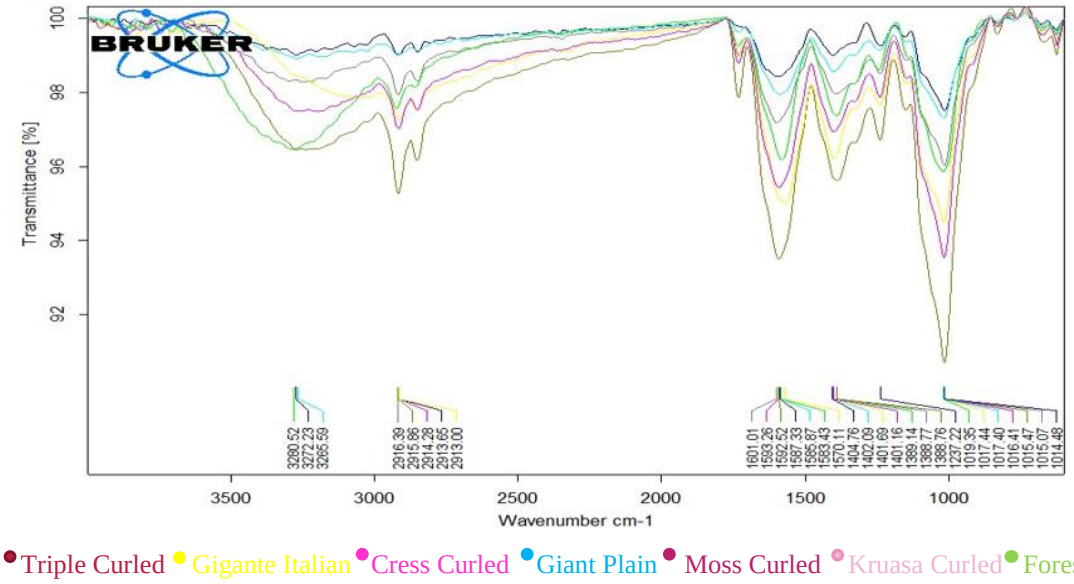
Notes: Means with a similar uppercase letter in the same column are not significantly different; p value by permutation ($p < 0.05$).

3.4. FTIR (Fourier transform infrared spectroscopy)

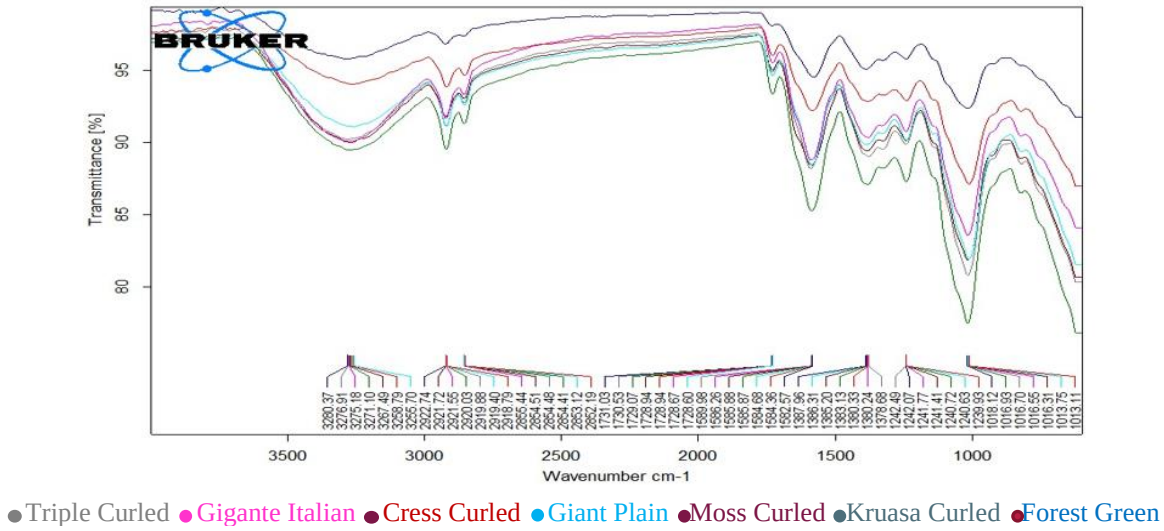
The Fourier transform infrared spectroscopy study revealed the existence of diverse functional groups in different parsley genotypes and farming systems. The FTIR spectra (Table 6, Figure 1A) exhibited distinct absorption peaks, including a wide peak at 3280 cm^{-1}, due to the -OH stretching of aromatic rings, in parsley genotypes except Triple Curled. A sharp peak at 1018 cm^{-1} indicated C-O stretching in ethers and esters. In the moderate wavelength range, peaks between 1570-1601 cm^{-1} corresponded to C-C and C=C stretching of aromatic hydrocarbons and conjugated alkenes in most polyhouse-grown genotypes. Additionally, an amide band at 1732 cm^{-1}, representing C=O stretching of ester groups, was observed in all genotypes except Triple Curled and Giant Plain genotype. Other notable peaks included 1394-1401 cm^{-1} (C-H bending in CH_2 and CH_3 groups) and 1236-1242 cm^{-1} (C-N stretching of aromatic amines), highlighting the presence of various functional groups in parsley genotypes were observed under polyhouse conditions.

The FTIR spectra of parsley genotypes grown in the NFT system (Table 7, Figure 1B) revealed distinct absorption peaks. A broad peak at 3255-3280 cm^{-1} was attributed to -OH stretching of aromatic rings, while a sharp peak at 1013-1018 cm^{-1} indicated C-O stretching in ethers and esters. Peaks at 1584-1589 cm^{-1} corresponded to C-C and C=C stretching of aromatic hydrocarbons and conjugated alkenes. Additionally, amide bands at 1728-1730 cm^{-1} (C=O stretching of ester groups) and 1239-1242 cm^{-1} (C-N stretching aromatic amines) were observed in all parsley genotypes. Further analysis revealed

additional functional groups in the parsley genotypes. The genotype-specific variations were observed, with Kruasa Curled exhibiting sharp peaks, while Triple Curled and Forest Green genotype showed narrow peaks under both polyhouse and NFT farming systems.



(A)



(B)

Figure 1. FT-IR spectra of parsley genotypes under (A) polyhouse condition and (B) Nutrient Film Technique farming system.

Table 6. FT-IR spectra showing the identified peaks and possible functional groups in the parsley genotypes under polyhouse condition.

Functional groups	Genotypes Wave number (peak position in cm^{-1})							Compound identification
	Triple Curled	Gigante Italian	Cress Curled	Giant Plain	Moss Curled	Kruasa Curled	Forest Green	
OH Stretching	-----	1401.20	3275.52	1401.13	3255.35	3250.37	3280.37	Alcohol, phenols, carboxylic acid
C-H Stretching	2920.10	2912.96 2849.47	2914.36 2849.26	2909.48 2847.28	2916.47 2849.22	2920.87 2848.44	2922.14	Alkanes, asymmetric and symmetric vibrational stretching of aliphatic –CH2 and –CH3 group
C-H Bending	1394.89	1401.20	1398.61	1401.13	1387.50	1401.20	1387.96	Bending in –CH2 and –CH3 group
C=O Stretching	-------	1732.11	1730.75	----	1729.24	1732.11	1731.03	Stretching in carbonyl group of aldehydes, amide ketones, esters and carboxylic acids
C-O Stretching	1236.89 1151.81 1017.87	1239.10 1017.07	1238.27 1015.88	1242.07 1016.94	1238.01 1014.54	1239.10 1014.95	1242.07 1018.12	Stretching in ethers, esters and ketones
C=C Stretching	1559.35	1564.54	1586.71	1585.48	1595.92	1587.93	1582.57	Conjugated alkenes, Aromatic hydro-carbons (Benzene)
C-C Stretching	1559.35	1564.54 1401.20	1586.71	1585.48 1401.13	1595.92	1587.93	1582.57	Aromatic hydro-carbons(benzene), Carbohydrates
C-N Stretching	1236.89 1151.81	1239.10	1238.27	1240.07	1238.01	1241.41	1242.07	Aliphatic and aromatic amines
N-O Stretching	1394.89	1401.20 1239.10	1398.61 1238.27	1401.13 1240.47	1387.50 1238.01	1401.2 1240.47	1387.96 1242.07	Nitro-alkanes, nitro group attached to an aromatic ring

Table 7. FT-IR spectra showing the identified peaks and possible functional groups in the parsley genotypes under Nutrient Film Technique farming system.

Functional Groups	Genotypes Wave number (peak position in cm^{-1})							Compound identification
	Triple Curled	Gigante Italian	Cress Curled	Giant Plain	Moss Curled	Kruasa Curled	Forest Green	
OH Stretching	3276.91	3275.18	3258.79	3255.70	3267.49	3271.10	3280.37	Alcohol, phenols, carboxylic acid
C-H Stretching	2919.88 2854.48	2921.55 2855.44	2918.79 2852.79	2919.40 2853.12	2921.72 2854.51	2920.03 2854.41	2922.14	Alkanes, asymmetric and symmetric vibrational stretching of aliphatic –CH2 and –CH3 group
C-H Bending	1378.68	1380.24	1380.33	1386.31	1385.20	1383.13	1387.96	Bending in –CH2 and –CH3 group
C=O Stretching	1730.53	1728.67	1728.94	1728.60	1728.94	1729.07	1731.03	Stretching in carbonyl group of aldehydes, amide ketones, esters and carboxylic acids
C-O Stretching	1242.49 1016.70	1241.77 1016.55	1239.33 1013.11	1240.63 1013.75	1241.41 1016.31	1240.72 1016.93	1242.07 1018.12	Stretching in ethers, esters and ketones
C=C Stretching	1589.98	1586.26	1584.36	1584.68	1585.88	1585.87	1582.57	Conjugated alkenes, Aromatic hydro-carbons (Benzene)
C-C Stretching	1589.98	1586.26	1584.36	1584.68	1585.88	1585.87	1582.57	Aromatic hydro-carbons(benzene), Carbohydrates
C-N Stretching	1242.49	1241.77	1239.33	1240.63	1241.41	1240.72	1242.07	Aliphatic and aromatic amines
N-O Stretching	1378.68 1242.49	1380.24 1241.77	1380.33 1239.33	1386.31 1240.63	1385.20 1241.41	1383.13 1240.72	1387.96 1242.07	Nitro-alkanes, nitro group attached to an aromatic ring

4. DISCUSSION

This study presents a comprehensive analysis of nutritional and mineral content in seven parsley genotypes grown under polyhouse and hydroponic (NFT) conditions at CSKHPKV, Palampur, Himachal Pradesh. The results show that moisture content was higher in most genotypes grown in the hydroponic NFT farming system, likely due to the constant supply of water and nutrients (Prabhas et al., 2023). Particularly, the Gigante Italian genotype exhibited the highest moisture content in both farming systems, possibly due to its flat, large leaf structure with greater water-holding capacity. The findings align with previous studies of El-Hadidy et al. (2019), who reported higher moisture content in flat-leaf parsley compared to curled-leaf parsley. Ash content, a crucial indicator of mineral content varied among genotypes and cultivation systems. The genotype Kruasa Curled exhibited higher (13.00 ± 0.40%) ash content in polyhouse conditions, while genotype Triple Curled (12.13 ± 0.40%) showed higher ash content in the hydroponic NFT system. Our findings are consistent with

Fernandes et al. (2020), who reported higher ash content in genotypes grown under soil conditions compared to other farming systems. Similar results were observed by Lei and Engeseth (2021), who observed lower ash content in hydroponically grown lettuce plant than soil grown lettuce.

The highest fat content (2.20 ± 0.02%) was observed in the genotype Gigante Italian in polyhouse conditions, possibly due to its optimal nutrient availability. However, the hydroponic NFT system showed promising results for crude protein content, with Giant Plain exhibiting higher levels. This aligns with Fernandes et al. (2020), who reported protein content ranging from 11.52 ± 0.06 % to 12.22 ± 0.04 % in parsley genotypes. The higher protein content in hydroponic systems may be because of optimized nutrient delivery and controlled environment, as suggested by Ranganath et al. (2023). Moreover, the mineral composition of parsley genotypes was significantly influenced by the cultivation system. The K (2.60 - 4.42%), Ca (3.01 - 3.62%), Fe (794.80 - 1541.80 mg/kg), Mn (12.60 - 29.90 mg/kg), Zn (81.55 - 144.15 mg/kg), and Cu (3.50-19.05 mg/kg) content was highest in most genotypes grown in the NFT hydroponic farming system. This may be attributed to the precise control over nutrient delivery in hydroponic systems, allowing for optimal mineral uptake by plants (Powlson et al., 2011). Our findings are supported by Saha et al. (2016), who reported higher Fe content in herbs grown under hydroponic systems compared to other farming methods.

Awad et al. (2017), also reported that NFT hydroponic systems enhance the mineral and nutritional status of leafy vegetables, particularly increasing Mn, Fe, Mg, and Zn content. Furthermore, vitamin C, an essential nutrient with antioxidant properties (Rucker et al., 2007), was found to be highest in most genotypes grown in the NFT hydroponic farming system. The increased vitamin C content in hydroponically grown parsley may be attributed to the balanced and optimal nutrient levels provided by the hydroponic system, as suggested by Buchanan et al. (2013). They reported that hydroponically grown herbs had higher ascorbic acid content compared to their soil-grown counterparts, likely due to the controlled nutrient delivery in hydroponic systems. This precise control enables plants to takes the necessary nutrients element, leading to enhanced vitamin C production and overall nutritional quality.

FTIR profiling was analysed to identify the functional groups present in different parsley genotypes and farming systems. The variations in peak intensity on the FTIR spectra (Figures 2 and 3) revealed distinct differences among genotypes, indicating unique chemical compositions. Our results confirmed the presence of diverse functional groups, comprise alcohol, alkane, aromatic compounds, alkene, aliphatic and aromatic amines, in parsley grown under NFT and polyhouse conditions. These findings are consistent with Fritea et al. (2017), who reported similar functional groups in parsley, including -OH stretching of the aromatic ring (3280 cm^{-1}), C=O stretch of the ester group (1636 cm^{-1}), C-H asymmetric bending in CH_2 and CH_3 groups (1394 cm^{-1}), secondary -OH bending (1220 cm^{-1}), and N-H bending (1530 cm^{-1}). The FTIR analysis detected the intensity of absorption spectra related with molecular constitution or presence of various functional groups, providing valuable insights into the chemical structure of parsley. The differences in peak intensity among genotypes and farming systems suggest variations in the chemical composition of parsley, which may be attributed to factors such as nutrient availability, genotype, and growing conditions (Bobby et al., 2012).

5. CONCLUSION

This study demonstrates that hydroponic and soil-based systems can produce nutritionally rich parsley, with distinct differences in nutritional and mineral profiles. Our findings highlight the importance of genotype selection and growing conditions in determining the nutritional quality of parsley. Particularly, hydroponic systems resulted in higher Fe content in certain genotypes, making parsley a valuable crop for addressing iron-deficiency anaemia. The variations in moisture and fat content between growing systems also have implications for parsley's shelf life and nutritional value. These findings contribute to the expanding knowledge on the potential of hydroponic systems to enhance crop nutritional quality, providing valuable insights for optimizing parsley production and informing future research on sustainable and nutritious food systems. Furthermore, it is important to explore in-depth hydroponic production and enhances its capability to ensure high – quality produce, as well as choose of appropriate genotypes that improved hydroponic products.

Author Contribution
Pushpa Guleria – Original draft preparation, Pardeep Kumar – Conceptualization, Parveen Kumar, Maneesha Devi, Purnima Sharma – reviewing and editing. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest There is no conflict of interest about this research manuscript.

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