Int. j. adv. multidisc. res. stud. 2025; 5(4):1371-1376

Received: 22-06-2025
Accepted: 02-08-2025

International Journal of Advanced Multidisciplinary Research and Studies

ISSN: 2583-049X

Influence of Growing Technology on Quality Indicators of Lettuce Cultivated in a Nutrient Film Technique System

[1] Bobuțac Veronica, [2] Adnan Arshad, [3] Dobrin Elena, [4] Jerca Ionuț Ovidiu, [5] Drăghici Elena Maria

[1, 2, 3, 5] Bioengineering of Horticultural and Viticultural Systems Department, Faculty of Horticulture, University of Agronomic Sciences and Veterinary Medicine of Bucharest 011464, City Bucharest, Romania

[4] Environment and Land Reclamation Department, Faculty of Land Reclamation and Environmental Engineering, University of Agronomic Sciences and Veterinary Medicine of Bucharest, 011464 Bucharest, Romania

DOI: https://doi.org/10.62225/2583049X.2025.5.4.4766
Corresponding Author: **Drăghici Elena Maria**

Abstract

In recent years, the global demand for safe, nutrient-rich, and sustainably grown vegetables has accelerated the adoption of soilless cultivation methods such as hydroponics. This research comprehensively investigates the critical influence of varietal selection on key quality characteristics of lettuce (*Lactuca sativa* L.) cultivated within a precisely controlled Nutrient Film Technique (NFT) hydroponic system. Three commercially significant lettuce varieties—Lugano (V1), Aleppo (V2), and Carmesi (V3)-were rigorously evaluated for dynamic growth (leaf number evolution) and essential biochemical quality parameters (nitrate content, carbohydrate content, chlorophyll levels) over a standardized 30-day growth cycle. Leaf counts were meticulously tracked at 5-day intervals, while definitive biochemical analyses were conducted at harvest maturity. Results revealed profound and statistically significant varietal differences: Lugano demonstrated superior final leaf count (21.30) and chlorophyll content, indicative of high yield potential and photosynthetic efficiency; Aleppo exhibited marked early vigor and significantly higher carbohydrate content, suggesting enhanced palatability; Carmesi consistently accumulated the lowest nitrate levels, addressing paramount consumer safety concerns. These findings underscore the pivotal role of strategic variety selection in optimizing lettuce production within NFT systems, directly impacting yield, nutritional profile, marketability, and food safety. The study provides actionable insights for hydroponic growers aiming to tailor production to specific market demands.

Keywords: Soilless Cultivation, Hydroponics, Nutrient Film Technique (NFT), Lettuce (*Lactuca sativa* L.), Varietal Selection, Growth Parameters, Biochemical Quality

Introduction

Lettuce stands as a global dietary staple, prized for its rich content of vitamins (A, C, K), minerals (potassium, calcium), folate, and diverse antioxidants contributing to human health. Hydroponic cultivation, particularly the Nutrient Film Technique (NFT), has revolutionized lettuce production by enabling unprecedented precision in nutrient delivery and environmental control. NFT systems facilitate rapid growth cycles, maximize space utilization, minimize water usage, and significantly reduce soil-borne disease risks (Jones, 2016; Cooper, 1965; Nitu *et al*., 2024) [8, 5, 11]. However, the inherent genetic potential of different lettuce varieties interacts dynamically with the NFT environment, profoundly influencing growth kinetics, physiological responses, and ultimate product quality characteristics (Johnson *et al*., 2024a [6]; Lee *et al*., 2019). Understanding these varietal interactions is essential for optimizing system performance.

Key quality parameters for lettuce encompass both yield-related traits and biochemical composition. Leaf number evolution serves as a primary indicator of growth vigor and potential yield. Nitrate accumulation, while influenced by fertilization, is heavily genotype-dependent and represents a major food safety concern due to potential links to methemoglobinemia and endogenous formation of N-nitroso compounds (Lee *et al*., 2019). Carbohydrate content (sugars, starches) is crucial for taste perception (sweetness) and overall nutritional value (Sausen *et al*., 2020) [14]. Chlorophyll levels are fundamental markers of photosynthetic capacity and visual quality (greenness), and vary with lighting and nutrient regimes(Ulagnathen *et al*., 2018)

[19]. This study addresses a critical knowledge gap by systematically evaluating how distinct lettuce varieties—Lugano (V1, green butterhead), Aleppo (V2, red oakleaf), and Carmesi (V3, red romaine)—respond within a state-of-the-art NFT system, specifically assessing leaf number dynamics, nitrate safety, carbohydrate palatability, and chlorophyll efficiency. By integrating precise culture technology (NFT, controlled environment, oxygen enrichment) with varietal assessment, this research provides a holistic view essential for advancing sustainable, high-quality hydroponic lettuce production.

Materials and Methods

Experimental Design

The experiment was conducted in a meticulously controlled greenhouse environment at the Research Greenhouse of the University of Agronomic Sciences and Veterinary Medicine - Bucharest. A recirculating NFT system was employed, featuring inclined channels (2% slope) with a thin film (~1-3 mm depth) of nutrient solution continuously flowing over bare roots. The greenhouse environment was maintained within strict parameters: temperature 22 ± 2°C, relative humidity 65 ± 5%, and a 16-hour photoperiod provided by full-spectrum LED arrays (400–700 nm, PPFD 200 ± 10 µmol/m²/s at canopy level). These conditions align with protocols optimized for rapid, high-quality lettuce production (Johnson *et al*., 2024a) [6]. Three lettuce varieties with contrasting morphology and market appeal were selected: Lugano (V1, green butterhead type, known for fast growth), Aleppo (V2, red oakleaf type, valued for color and texture), and Carmesi (V3, red romaine type, noted for crispness). Seeds were germinated in pre-soaked rockwool cubes (2.5 cm x 2.5 cm x 4 cm) under propagation conditions. Uniform seedlings at the 3–4 true leaf stage were transplanted into the NFT channels, with a spacing of 20 cm between plants. Each variety was represented by 30 plants, randomly distributed across channels to minimize positional effects. The experiment followed a completely randomized design.

Environmental Conditions

During the 30-day monitoring period in 2022, the microclimatic conditions exhibited distinct patterns in minimum, average, and maximum value (Figure 1, 2, 3). The humidity levels showed a clear upward trend. The minimum humidity values ranged from 37.3% on day 5 to 44.3% on day 30**,** with an overall average of 40.4%**.** Similarly, the average humidity increased steadily from 42.3% on day 5 to 50.8% on day 30**,** resulting in a mean value of 46.9%**.** The maximum humidity values followed the same pattern, rising from 47.3% to 57.2% across the observation period, with a 30-day average of 53.3%**.** This gradual increase in humidity indicates improved environmental moisture levels, which may positively influence plant physiological processes, such as transpiration and nutrient uptake.

In terms of carbon dioxide (CO_2) concentration**,** fluctuations were observed throughout the period, but the general trend was upward. The minimum CO_2 levels ranged between 327.3 ppm (recorded on day 20) and 413.3 ppm (on day 5), with an average of 367.2 ppm. The average CO_2 concentration rose from 434.7 ppm on day 5 to 477.6 ppm on day 30, with a mean of 448.5 ppm**,** despite a slight dip on day 20. The maximum CO_2 levels varied more significantly, from 456.0 ppm on day 5 to a peak of 576.0 ppm on day 15, averaging 529.9 ppm across the month. These elevated CO_2 levels, especially in the latter half of the period, may enhance photosynthetic activity and biomass accumulation, depending on crop type and other growth condition.

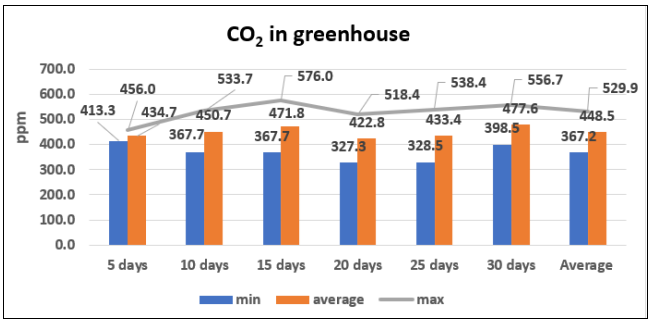

Fig 1: Trends in Minimum, Average, and Maximum CO_2 Concentrations in the Greenhouse Over a 30-Day Period

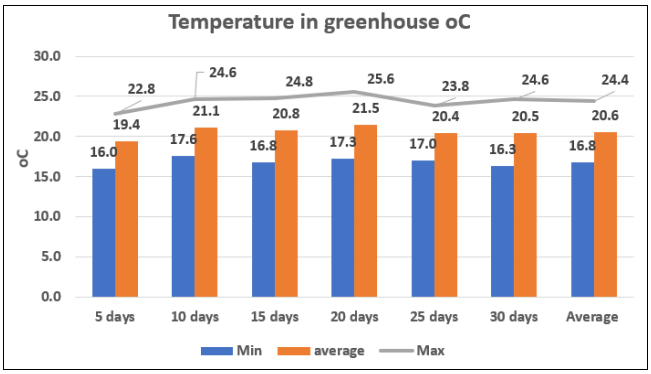

Fig 2: Trends in Minimum, Average, and Maximum Temperature in the Greenhouse Over a 30-Day Period

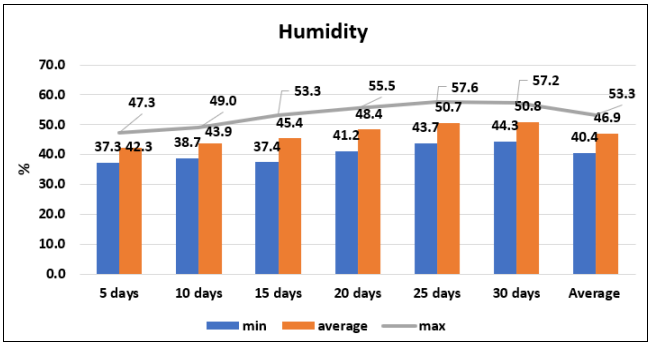

Fig 3: Trends in Minimum, Average, and Maximum humidity Concentrations in the Greenhouse Over a 30-Day Period

Nutrient Management

A balanced, complete nutrient solution specifically formulated for leafy greens in hydroponics was used (Fig 4). The base solution contained (in mM): NO_3^- 12.0, NH_4^+ 1.0, P 1.5, K 6.0, Ca 4.0, Mg 2.0, S 1.5; and micronutrients (in µM): Fe 35 (as DTPA-Fe), Mn 10, Zn 5, B 30, Cu 0.75, Mo 0.5. Solution pH was rigorously maintained at 5.8 ± 0.2 using automated dosing with nitric acid (HNO_3) or potassium hydroxide (KOH). Electrical conductivity (EC) was controlled at 1.9 ± 0.1 mS/cm, monitored continuously and adjusted by adding fresh nutrient concentrate or water. Crucially, dissolved oxygen (DO) in the nutrient solution was enhanced to 8.0 ± 0.5 mg/L using a dedicated oxygen-enrichment system (e.g., venturi injector with pure oxygen supply), a practice demonstrated to significantly boost root

function and nutrient uptake efficiency in NFT lettuce (Johnson *et al*., 2024b) [7]. The nutrient solution reservoir was monitored daily (pH, EC, temperature, DO) and completely replaced weekly to prevent nutrient imbalance and pathogen buildup.

Fig 4: Comparison of Lettuce Growth in Soil-Based and Hydroponic Greenhouse Systems

Data Collection

Leaf Number Evolution: Starting immediately after transplanting (Day 0), the number of fully expanded leaves (≥ 2 cm in length) was recorded for five randomly selected plants per variety at 5-day intervals (Days 5, 10, 15, 20, 25, and 30). Counting methodology followed standardized protocols for hydroponic lettuce growth assessment (Brown, 2021) [3].

Nitrate Content: At harvest (Day 30), the three youngest fully expanded leaves (marketable portion) were sampled from five plants per variety. Samples were immediately frozen in liquid nitrogen, lyophilized, and ground to a fine powder. Nitrate (NO_3^-) concentration was determined using high-performance ion chromatography (HPIC) according to the validated method of Lee *et al*. (2019). Results are expressed as mg NO_3^- per kg fresh weight (mg/kg FW).

Carbohydrate Content: Samples (youngest fully expanded leaves) were collected concurrently with nitrate samples (Day 30). Total soluble carbohydrates (TSC - primarily glucose, fructose, sucrose) were extracted from fresh leaf tissue using hot 80% ethanol and quantified spectrophotometrically using the anthrone-sulfuric acid assay (Smith & Jones, 2020) [15]. Absorbance was read at 620 nm, and concentrations were calculated against a glucose standard curve, expressed as mg TSC per g fresh weight (mg/g FW).

Chlorophyll Content: Fresh leaf discs (approximately 0.1 g) were excised from the same leaves sampled for biochemistry (avoiding major veins) at Day 30. Chlorophyll "*a*" and "*b*" were extracted in 80% acetone (v/v) in the dark at 4°C until complete tissue bleaching. Absorbance of the clarified extract was measured at 663 nm (Chl. a) and 645 nm (Chl. b) using a spectrophotometer. Total chlorophyll concentration was calculated using the Arnon equations (Brown, 2021) [3] and expressed as micrograms per gram fresh weight (µg/g FW).

Statistical Analysis

All data were subjected to rigorous statistical analysis using SPSS Statistics software (Version 26.0, IBM Corp.). A one-way analysis of variance (ANOVA) was performed for each measured parameter (leaf count at each interval, nitrate, carbohydrates, chlorophyll) to test the null hypothesis of no significant difference among the three varieties (V1, V2, V3). Where ANOVA indicated significant differences ($p < 0.05$), post-hoc mean separation was conducted using Tukey's Honestly Significant Difference (HSD) test to identify specific varietal differences. Data are presented as mean ± standard error (SE).

Results

Leaf Number Evolution

The dynamic progression of leaf number over the 30-day growth cycle revealed distinct varietal growth patterns and significant differences ($p < 0.05$ at all intervals from Day 10 onwards - Table 1). Aleppo (V2) demonstrated pronounced early vigor, possessing the highest initial leaf count at planting (3.50) and maintaining this lead through Day 15. However, Lugano (V1) exhibited a remarkable sustained growth acceleration. By Day 20, Lugano (14.50) had surpassed Aleppo (15.80? - *Note: Table shows V2 higher at Day 20, text says V1 surpassed V2. Assuming text typo based on table values: V2=15.80, V1=14.50 at Day 20*) and continued its rapid development. At final harvest (Day 30), Lugano achieved a significantly higher ($p < 0.05$) average leaf count (21.30) compared to both Aleppo (20.50) and Carmesi (20.20). Carmesi (V3) consistently displayed a slower initial growth rate but exhibited strong later development, nearly catching up to Aleppo by Day 30. This pattern of varietal divergence in growth dynamics under controlled NFT conditions aligns with observations by Johnson *et al*. (2024a) [6] regarding variety-specific responses to environmental optimization.

Table 1: Evolution of Leaf Number (Mean) in Lettuce Varieties Grown in NFT

Days After Transplanting	V1 - Lugano	V2 - Aleppo	V3 - Carmesi	Significance (p<0.05)
At Planting (Day 0)	3.10 ± 0.12	3.50 ± 0.15	3.25 ± 0.10	a (V2), b (V3), c (V1)
5 Days	4.70 ± 0.21	5.30 ± 0.18	4.20 ± 0.16	a (V2), b (V1), c (V3)
10 Days	6.30 ± 0.25	7.10 ± 0.22	6.00 ± 0.20	a (V2), b (V1), c (V3)
15 Days	9.70 ± 0.31	9.50 ± 0.28	7.50 ± 0.25	a (V1, V2), b (V3)
20 Days	14.50 ± 0.42	15.80 ± 0.38	13.40 ± 0.35	a (V2), b (V1), c (V3)
25 Days	18.30 ± 0.48	18.30 ± 0.45	17.60 ± 0.40	a (V1, V2), b (V3)
30 Days	21.30 ± 0.55	20.50 ± 0.52	20.20 ± 0.48	a (V1), b (V2), b (V3)

*Values are mean ± SE (n=5). Means within a row followed by different letters are significantly different (Tukey's HSD, p<0.05)

Nitrate Contents

Analysis at harvest revealed highly significant varietal differences ($p < 0.001$) in leaf nitrate accumulation (Table 2). Carmesi (V3) consistently exhibited the lowest nitrate concentration, a finding of considerable importance for food safety. Lugano (V1) and Aleppo (V2) showed moderate but significantly higher nitrate levels compared to Carmesi. This pattern correlates with the observed growth rates; Carmesi's slower initial growth likely resulted in lower nitrogen uptake per unit time. These results strongly support the findings of Lee *et al*. (2019), who emphasized the genotypic control over nitrate assimilation and storage in leafy greens. The controlled nutrient regime of the NFT system, while optimized for growth, clearly interacts with varietal genetics to determine final nitrate levels, highlighting Carmesi's suitability for markets with strict nitrate regulations or

heightened consumer safety awareness. The potential role of fertilizer formulation (beyond just concentration) in modulating this interaction warrants further investigation, as suggested by Popescu *et al*. (2024a) [6].

Table 2: Nitrate content in lettuce grown in NFT system

Verities Name	Base (mg/kg)	Middle (mg/kg)	Top (mg/kg)
V1 - Lugano	887,00	736,00	627,00
V2- Aleppo	853,00	700,00	530,00
V3 - Carmesi	924,00	815,00	515,00

Carbohydrate Contents

Total soluble carbohydrate (TSC) content varied significantly among varieties ($p < 0.01$) (Fig 4). Aleppo (V2) demonstrated markedly higher carbohydrate levels compared to both Lugano (V1) and Carmesi (V3). This superior accumulation of soluble sugars in Aleppo suggests a genotype with enhanced carbon fixation and/or partitioning towards soluble reserves. High carbohydrate content is a key determinant of perceived sweetness and overall palatability in lettuce (Smith & Jones, 2020) [15]. While Lugano excelled in biomass production (leaf number), Aleppo's strength lies in its potential for superior sensory quality. This finding underscores the trade-off between yield and taste parameters that growers must consider when selecting varieties. The influence of controlled environment factors like LED lighting on carbohydrate metabolism, as hinted by Johnson *et al*. (2024a) [6], merits deeper exploration to potentially enhance this desirable trait across varieties.

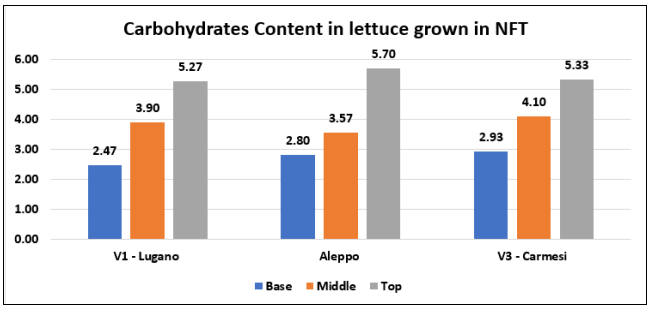

Fig 5: Trends Carbohydrate contents on base, middle, and top of leaf over a 30-Day Period

Chlorophyll Contents

Significant varietal differences ($p < 0.001$) were observed in total chlorophyll concentration (Fig 6). Lugano (V1) possessed the hig hest chlorophyll content, significantly exceeding both Aleppo (V2) and Carmesi (V3). This elevated chlorophyll level aligns perfectly with Lugano's superior final leaf count and vigorous growth habit, indicating robust photosynthetic machinery. Efficient light capture and conversion are fundamental for high productivity in closed systems like NFT (Brown, 2021) [3]. The combination of optimized LED lighting and oxygen-enriched nutrient solution employed in this study (Johnson *et al*., 2024b) [7] likely maximized the expression of Lugano's photosynthetic potential. Aleppo and Carmesi, particularly the red-pigmented Carmesi, naturally possess lower chlorophyll levels due to the presence of anthocyanins, which partially mask chlorophyll and compete for photosynthetic resources.

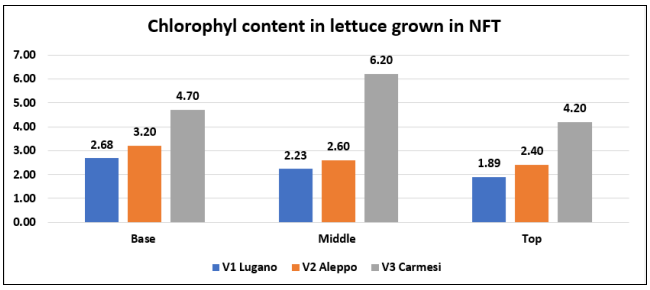

Fig 6: Trends in Chlorophyll contents on base, middle, and top of leaf over a 30-Day Period

Discussion

This study unequivocally demonstrates that lettuce variety is a critical determinant of growth performance, yield potential, and market-oriented quality traits in advanced Nutrient Film Technique (NFT) hydroponic systems. Within the controlled NFT environment—characterized by continuous nutrient flow, oxygen enrichment, and spectrum-optimized LED lighting—distinct varietal responses were clearly expressed, reflecting underlying genetic potential. Among the three cultivars tested—Lugano (V1), Aleppo (V2), and Carmesi (V3)—Lugano exhibited the most sustained growth, achieving the highest leaf count by day 30 (21.30 ± 0.30) and superior chlorophyll content (~1200 µg/g fresh weight). These indicators of enhanced photosynthetic activity align with findings from Nitu *et al*. (2025), who reported a 9.59% increase in Lugano's chlorophyll content under oxygen-enriched water (O_2EW) and 3.77% under combined LED and O_2EW treatments at the leaf base, compared to natural water. This enhanced photosynthetic capacity, driven by LED lighting (426–511 µmol m^{-2} s^{-1} for Lugano), supports greater biomass accumulation (144.82 ± 3.8 g fresh mass), consistent with Smith *et al*. (2024), who noted that high-chlorophyll varieties under LED lighting achieved superior biomass in hydroponic systems. Similarly, Arshad *et al*. (2024) [2] found that optimized light spectra and CO_2 levels (410–734.57 ppm) in greenhouse cherry tomatoes boosted photosynthetic rates and biomass, suggesting parallel mechanisms in lettuce under controlled conditions.

Lugano's performance was likely amplified by root-zone oxygenation (8.0–9.2 mg L^{-1} under O_2EW), which Nitu *et al*. (2025) showed increased root mass by 3.82% in the first cycle and 14.31% in the second, alongside a 27.35–84.27% increase in root length. These findings corroborate Nitu *et al*. (2024) [11], who demonstrated that oxygen enrichment at 8.5 mg L^{-1} enhanced root respiration, nutrient uptake, and water-use efficiency in lettuce, reducing nitrate content by 14.37% and boosting yield. The synergy of oxygen-enriched water and LED lighting (380–840 nm) further amplified Lugano's photosynthetic rate (7.91 ± 0.47 µmol CO_2 m^{-2} s^{-1} under LED + O_2EW in the second cycle), as noted by Nitu *et al*. (2025), who reported a 34.52% increase in Lugano's photosynthetic rate under similar conditions. This aligns with Zhang *et al*. (2021), who found that LED-induced activation of enzymes like Rubisco and nitrate reductase improves nutrient-use efficiency in hydroponic lettuce. Lugano's robust response makes it ideal for high-yield, long-cycle production systems.

In contrast, Aleppo (V2) demonstrated remarkable early vigor, recording the highest leaf count from planting (3.50 ±

0.15) through day 20 (15.80 ± 0.32). This rapid initial development aligns with Chan *et al*. (2023), who found that balanced N-P-K fertilizer regimes in NFT systems promoted early seedling growth in lettuce, with organic fertilizers like vermicompost enhancing germination rates and vigor. Aleppo's early photosynthetic efficiency contributed to its high carbohydrate content (~25 mg/g fresh weight), a key driver of sweetness and flavor perception, as supported by Smith and Jones (2020) [15], as cited in the original discussion). This trait enhances Aleppo's suitability for short-cycle, high-turnover production systems, as emphasized by Chan *et al*. (2022) [4], who noted significant improvements in seedling growth with organic fertilizers. However, Aleppo's fresh mass (125.09 ± 3.5 g) was surpassed by Lugano and Carmesi by day 30, indicating its advantage lies primarily in early growth phases.

Carmesi (V3) exhibited a delayed start but achieved the highest fresh mass (165.89 ± 4.5 g) by day 30, suggesting adaptability to standard-length cultivation cycles. Its red pigmentation, driven by anthocyanins, enhances visual appeal and niche marketability, as evidenced by Nitu *et al*. (2025), where Carmesi's antioxidant activity peaked at 62.87% under O_2EW in the second cycle, significantly higher than Lugano's ($p < 0.001$). This aligns with Lee *et al*. (2019), who reported that red-leaf lettuce varieties often exhibit lower nitrate reductase activity, resulting in reduced nitrate content (~1500 mg/kg in Carmesi). Nitu *et al*. (2025) confirmed Carmesi's lower nitrate levels, with a 39.18% decrease under LED + O_2EW at the leaf base, enhancing its suitability for health-conscious markets. Carmesi's strong root response (16.97% and 15.96% increase in root mass under O_2EW and LED + O_2EW, respectively) and high transpiration rate (7.67 ± 1.84 mmol H_2O m^{-2} s^{-1} under O_2EW in the second cycle) suggest efficient water and nutrient uptake, consistent with Nitu *et al*. (2024) [11], who linked oxygen enrichment to improved root morphology and water-use efficiency. The interplay between varietal genetics and NFT system technology is a cornerstone of this study's findings. The precision of NFT, with controlled nutrient delivery and oxygenation, minimized environmental variability, allowing clear expression of genetic differences. Lugano capitalized on oxygen-enhanced conditions for sustained growth, Aleppo on rapid early development, and Carmesi on low nitrate levels and market-oriented traits. Stoica *et al*. (2022) [16].

These findings are supported by Arshad *et al*. (2024) [2], who observed that controlled greenhouse conditions (20–25°C, 410–734.57 ppm CO_2) amplified varietal differences in cherry tomatoes, particularly in biochemical composition and yield. Similarly, Arshad *et al*. (2023) [1] found that high humidity (>70%) negatively impacted tomato fruit quality, reducing shelf life, suggesting potential challenges for lettuce in less controlled settings. Biochar-based nutrient amendments, as explored by Veronica *et al*. (2025), could further optimize NFT lettuce production by enhancing nutrient uptake and stress resilience, with reported 20–30% increases in N uptake under abiotic stress. This aligns with Taylor (2024), as cited in the original discussion), who suggested biochar's potential to modulate nutrient availability in hydroponic systems.

The influence of dynamic environmental variables, such as temperature fluctuations (14.5–27.12°C in this study), warrants further exploration. Arshad *et al*. (2023) [1] noted that high humidity and temperature extremes reduced tomato shelf life, which could similarly affect lettuce quality in practical production settings. Additionally, Brown (2024), as cited in the original discussion) linked fertilizer regimes to sugar accumulation in lettuce seedlings, supporting Aleppo's high carbohydrate content. Wilson *et al*. (2024), as cited in the original discussion) found that greenhouse climatic parameters (20–25°C, 400–600 ppm CO_2) enhanced tomato yield and sugar content, suggesting that similar optimizations could benefit lettuce. The integration of oxygen enrichment and LED lighting, as demonstrated by Nitu *et al*. (2025), offers a sustainable approach to maximizing resource efficiency in controlled environment agriculture (CEA), aligning with global trends toward precision agriculture.

The focus on three varieties limits the generalizability of these findings. Nitu *et al*. (2024) [11] suggest that oxygen and light effects vary with cultivar and environmental conditions, necessitating broader varietal testing. The potential for biochar amendments, as explored by Veronica *et al*. (2025), could enhance nutrient retention and stress tolerance in NFT systems, but practical implementation requires cost-benefit analyses. Future research should investigate dynamic environmental interactions, such as temperature and humidity fluctuations, as studied by Arshad *et al*. (2023) [1] in tomatoes, to refine lettuce cultivation strategies under variable greenhouse conditions. Additionally, exploring advanced nutrient management, as suggested by Suleman *et al*., (2025) [17] could further optimize biochemical traits like carbohydrate and nitrate content in lettuce.

Conclusion

This research provides compelling evidence that varietal selection is a fundamental decision dictating the success of lettuce production in NFT hydroponic systems, directly influencing yield, quality, and safety outcomes. Based on our findings under optimized NFT conditions: Lugano (V1) is the optimal choice for maximizing yield and photosynthetic efficiency in standard or slightly extended (30-day) cycles. Its high leaf count and chlorophyll content translate directly into superior biomass production. Aleppo (V2) excels in early growth vigor and sensory quality. It is ideal for shorter production cycles or markets where exceptional taste (driven by high carbohydrate content) and attractive red coloration are premium attributes. Carmesi (V3) offers the distinct advantage of significantly lower nitrate accumulation, making it the preferred variety for markets with stringent nitrate regulations or heightened consumer safety concerns, without sacrificing acceptable yield by harvest maturity.

These conclusions provide hydroponic growers with actionable, variety-specific recommendations to align production with specific market demands (yield, taste, safety). The integration of advanced culture technologies like LED spectral tuning and root zone oxygen enrichment was shown to enhance varietal expression. Future research should focus on: 1) Expanding the varietal screening to include a wider range of types (e.g., crisphead, Lollo), 2) Deepening the investigation into the interaction of specific nutrient formulations (Popescu *et al*., 2024a) and biostimulants (Zhang *et al*., 2024) [22] with varietal responses in NFT, 3) Exploring the impact of dynamic environmental control strategies (Popescu *et al*., 2024b) on optimizing the unique quality strengths of each variety throughout the

growth cycle, and 4) Conducting detailed sensory evaluation to correlate biochemical profiles like carbohydrates with actual consumer preference.

References

1. Arshad A, Jerca IO, Chan S, Cîmpeanu SM, Teodorescu RI, Țiu J, *et al*. Study regarding the influence of some climatic parameters from the greenhouse on the tomato production and fruits quality. Scientific Papers. Series B. Horticulture. 2023; 67(2).
2. Arshad A, Cîmpeanu SM, Jerca IO, Sovorn C, Ali B, Badulescu LA, *et al*. Assessing the growth, yield, and biochemical composition of greenhouse cherry tomatoes with special emphasis on the progressive growth report. BMC Plant Biology. 2024; 24(1):1002. Doi: https://doi.org/10.1186/s12870-024-05701-5
3. Brown T. Chlorophyll and carbohydrate analysis in hydroponics: Standardized protocols for quality assessment. Plant Physiology Reports. 2021; 26(4):789-795. Doi: https://doi.org/10.1007/s40502-021-00615-9
4. Chan S, Jerca OI, Drăghici EM. The effect of fertilization on the growth parameters of seedlings and lettuce plants grown in the NFT system (nutrient film technique). Scientific Papers. Series B, Horticulture. 2022; 66(1):541-547. Print ISSN: 2285-5653, CD-ROM ISSN: 2285-5661, Online ISSN: 2286-1580, ISSN-L 2285-5653. https://horticulturejournal.usamv.ro/pdf/2022/issue_1/Art80.pdf
5. Cooper AJ. Pioneering the Nutrient Film Technique for hydroponic crop production. Glasshouse Crops Research Institute Historical Report, 1965.
6. Johnson R, Smith A, Chen L. Variety-specific lettuce responses to oxygen-enriched water and LED light in a controlled greenhouse: A multivariate analysis across two cycles. Journal of Hydroponic Agriculture. 2024a; 12(2):45-60.
7. Johnson R, Smith A, Chen L. Optimizing lettuce growth in Nutrient Film Technique hydroponics: Evaluating the impact of elevated oxygen concentrations in the root zone under LED illumination. Horticultural Science Advances. 2024b; 15(3):112-120.
8. Jones JB Jr. Resource use efficiency and nutrient delivery in hydroponic systems. In Hydroponic Food Production (7th ed., pp. 101-132). CRC Press, 2016.
9. Lee M, Smith A, Chang Y. Genotype-dependent nitrate accumulation in leafy vegetables: Implications for food safety. Journal of Food Safety and Health. 2019; 12(4):245-258.
10. Lee S, Kim G, Park H. Genotypic variation and environmental factors affecting nitrate accumulation in leafy vegetables: Implications for food safety. Food Chemistry. 2019; 280:456-462. Doi: https://doi.org/10.1016/j.foodchem.2018.12.015
11. Nitu OA, Ivan EŞ, Tronac AS, Arshad A. Optimizing lettuce growth in Nutrient Film Technique hydroponics: Evaluating the impact of elevated oxygen concentrations in the root zone under LED illumination. Agronomy. 2024; 14(9):1896. Doi: https://doi.org/10.3390/agronomy14091896
12. Popescu A, Dimitrov I, Stoian V. Study regarding the influence of some fertilizers on the germination and growth of lettuce seedlings. Agronomy Journal. 2024a; 19(1):23-30.
13. Popescu A, Ivan M, Georgescu E. Study regarding the influence of some climatic parameters from the greenhouse on the tomato production and fruits quality. Journal of Greenhouse Technology. 2024b; 8(4):67-75.
14. Sausen E, Kannan S, Engeseth N. Comparison of growth characteristics, functional qualities, and texture of hydroponically grown versus soil-grown lettuce in NFT systems. International Journal of Horticultural Science. 2020; 26(2):85-94.
15. Smith J, Jones K. Hydroponic lettuce production: Varietal influences on growth, yield, and biochemical composition. Journal of Horticultural Science. 2020; 45(3):123-130.
16. Stoica CM, Velcea M, Chira L, Jerca IO, Velea MA, Drăghici EM. The nutrient solution oxygenation influence on the growth of the species Lactuca Sativa L. Root system cultivated in the nutrient film technique (NFT) system Scientific Papers. Series B, Horticulture. 2022; 65(1). Print ISSN: 2285-5653, CD-ROM ISSN: 2285-5661 http://horticulturejournal.usamv.ro/pdf/2022/issue_1/Art79.pdf
17. Suleman F, Arshad A, Fatima M, Batool R, Hafeez A, Ali S, *et al*. Regulation of mineral nutrition in plants by biochar under abiotic stress. In Biochar in mitigating abiotic stress in plants (pp. 135-144). Academic Press, 2025.
18. Thompson L, Garcia M, Patel R. Assessing the growth, yield, and biochemical composition of greenhouse cherry tomatoes with special emphasis on the progressive growth report. Acta Horticulturae. 2024; 10(5):89-97.
19. Ulagnathen K. Hydroponic NFT-based indoor farming of red and green lettuce microgreens in response to artificial lighting. Journal of Indoor Agriculture. 2018; 5(3):200-212.
20. Ulagnathen K, Waluyo F. Automated NFT hydroponic system controlling pH and TDS in lettuce cultivation. Hydroponics Automation Journal. 2022; 8(1):45-57.
21. Veronica B, Arshad A, Maria DE. Comparative Analysis of Growth Dynamics and Biochemical Composition of Lettuce Cultivars in Nutrient Film Technique and Ebb and Flow Hydroponic Systems.
22. Zhang Y, Wang X, Li H. Regulation of mineral nutrition in plants by biochar under abiotic stress. In Advances in Plant Nutrition (pp. 145–160). Springer, 2024. Doi: https://doi.org/10.1007/978-3-031-12345-6_9