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THE EFFECT OF ADDITIONAL OXYGENATION AND LED LIGHTING ON THE GROWTH OF LUGANO AND CARMESI LETTUCE VARIETIES CULTIVATED IN THE NFT SYSTEM

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Abstract

The oxygen concentration in the nutrient solution is extremely important for the health and development of plants, including lettuce. Lettuce plant roots perform respiration, a process through which they absorb oxygen and release carbon dioxide. This metabolic process is essential for providing the energy necessary for growth and optimal plant functioning. An adequate oxygen concentration in the nutrient solution is crucial for the roots to efficiently carry out this process. Insufficient oxygen concentration can lead to inefficient nutrient absorption, thus affecting plant growth and development. The purpose of this paper is to investigate the impact of different lettuce varieties and cultivation technologies on the average plant mass, length, and average root volume. It examines how various growth conditions, such as additional oxygenation and LED lighting, influence the development of lettuce plants, especially the Lugano and Carmesi varieties. By evaluating these factors, the paper aims to provide relevant information for optimizing agricultural practices in lettuce cultivation, with the goal of maximizing production and crop quality.

***Key words**: Oxygen, roots, nutrients, respiration, development.*

INTRODUCTION

Lettuce represents the most cultivated plant in the category of greens in hydroponic systems (Ohse et al., 2009; Ryder, 1999). In these systems, the lifecycle duration of lettuce is shorter compared to traditional cultivation systems. The NFT (Nutrient Film Technique) cultivation system is ideal for growing lettuce (*Lactuca sativa* L.), allowing for even eight harvests within a calendar year (Fussy & Papenbrock, 2022). In the context of hydroponic lettuce crops, it is recommended that nutrients be presented in the nutrient solution at the following concentrations: 200 mg/L (ppm) of nitrogen (N), 50 mg/L (ppm) of phosphorus (P), 300 mg/L (ppm) of potassium (K), 200 mg/L (ppm) of calcium (Ca), and 65 mg/L (ppm) of magnesium (Mg) (Schon, 1992).

Within unconventional cultivation systems, it is crucial that the nutrient solution contains all the essential nutrients for the growth of lettuce plants. A lack of these elements can lead to the emergence of physiological problems which, ultimately, affect the quality of the lettuce plants (Henry et al., 2019). Lettuce plants develop optimally when the dissolved oxygen content in the nutrient solution reaches at least 6 ppm. No significant variations were observed in terms of the appearance of the roots or the vegetative mass of the lettuce at any of the tested oxygen concentrations, ranging between 2.1 and 16.8 mg/L (Goto et al., 1996). Following the investigation on the impact of oxygen concentrations on hydroponic lettuce cultivation, Goto et al. (1996) concluded that a concentration equal to or less than 2.1 mg/L of dissolved oxygen is necessary to ensure adequate plant development.

The introduction of additional oxygen into hydroponic (NFT) lettuce crops positively influenced the harvest (Kratky, 2005). It was found that a flow rate of 1.5 L/min of the nutrient solution led to an increase in the vegetative mass of lettuce plants compared to flow rates of 0.75 L/min (Al-Tawaha et al., 2018).
The respiration of plant roots is influenced by several factors, including high temperature and salinity levels (Zinnen, 1988). In hydroponic cultivation systems, high temperatures of the nutrient solution and prolonged periods of heat have a negative effect on plant growth (Al-Rawahy et al., 2023; Micu et al., 2022).
Oxygen deficiency near the roots is a critical factor (Fagerstedt et al., 2023). The absence or insufficiency of oxygen can negatively influence the development of the root system and can even lead to its deterioration, which may cause plant desiccation (Boru et al., 2003).
The importance of the presence of oxygen in the root zone of plants throughout all stages of development has highlighted oxyfertigation as an accelerator of the effects of resources in a natural manner (Moreno et al., 2020). In hydroponic cultures, it is crucial to have an elevated level of dissolved oxygen (DO) to support healthy root respiration (Chun & Takakura, 1994). The importance of oxygen absorption using peroxides or peracetic acid in nutrient solutions to enhance the fresh mass in arugula (*Eruca sativa* Mill.) culture developed in a floating system was observed (Carrasco et al., 2011). Research conducted on lettuce grown in a hydroponic system demonstrated that oxygen supersaturation stimulates plant growth without affecting the chlorophyll in the leaves (Kurashina, 2019). Adjusting the water flow rate at the time of harvest can improve crop performance (Baiyin et al., 2021). However, following the results obtained, there is no justification for using a nutrient solution flow rate greater than 2.5 L/min (Stoica et al., 2022). A low oxygen content in the root zone can create favorable conditions for the onset of plant diseases (Cherif et al., 1997) and may promote the infestation of the root system with pathogens, such as *Phytophthora infestans* (Lal et al., 2018). LED lighting allows for the adjustment of the light spectrum to suit the needs of the plant. Red (R) and blue (B) lights are beneficial for photosynthesis. Various studies have investigated the effect of the R and B spectral components on the physiological, biochemical aspects, and resource use efficiency in lettuce plants (Draghici et al., 2013; Drăghici and Pele, 2013; Panter et al., 2014; Panter et al., 2016). Based on research conducted with red and blue light (RB) spectra at levels of 0.5, 1.2, 3, and 4, provided by LED lamps, compared to reference light from fluorescent lamps (with RB = 1) in six experimental variants, under controlled conditions (with PPFD = 215 μmol m^{-2} s^{-1}) and a 16-hour day length, it was found that LED lighting led to a 1.6 times increase in biological yield and a 2.8 times improvement in energy consumption efficiency compared to fluorescent lamps (Pennisi et al., 2019).

MATERIALS AND METHODS

The research was conducted at the University of Agronomic Sciences and Veterinary Medicine in Bucharest, in the greenhouse block of the Research Center for the Study of the Quality of Agri-Food Products. The lettuce varieties used in the experiment were Lugano and Carmesi, with the seeds having a quality assurance certificate for the biological material (Figure 1).

Figure 1. The Lugano and Carmesi varieties

They were cultivated in an NFT (Nutrient Film Technology) system, during the period January 19 - February 20, 2024. Additional oxygenation of the nutrient solution was achieved using a SERA AIR 550 R PLUS type pump for oxygen enrichment with a low electricity consumption of 8W, with an air flow rate of 9.2 l/min and 55 l/h (Figure 2).
The LED lighting system with specific wavelengths and photoperiod used in the experiment has the following characteristics: power 100W, water resistance rate IP67,

frequency 50 Hz/60 Hz, input voltage: AC 220V, wavelength Full Spectrum 380-840 nm.
The conducted experiment was of a 2 x 2 type with three repetitions. Factor A was represented by the two lettuce varieties Lugano and Carmesi, while Factor B represented the cultivation technology with the following gradations: b1-natural oxygenation, b2-additional oxygenation, b3- additional oxygenation plus LED Lighting (Table 1). Oxygen from other sources was not used in the experiment.

Table 1. Experimental Variants

Factor A	Factor B		
a_1 Lugano	b_1 natural oxygenation	b_2 additional oxygenation	b_3 additional oxygenation plus LED Lighting
a_2 Carmesi			

Planting in the NFT system was carried out on January 19, 2024. Climatic factors, such as light, atmospheric humidity, and temperature, as well as the temperature of the nutrient solution, were monitored throughout the entire vegetation cycle.
Observations and measurements dynamically focused on the evolution of the plants in terms of diameter growth and the formation of leaf numbers. After 30 days of planting in the NFT system, the plants were harvested, and the tested variants were weighed to determine their mass, while the length and volume of the roots were measured using an EPSON Flatbed Expression 11000X Scanner.

Figure 2. SERA AIR 550 R PLUS pump for oxygen enrichment

RESULTS AND DISCUSSIONS

The influence of lettuce varieties on the production of average mass (g) showed that the Lugano variety yielded 100.83 g, while the average mass of the Carmesi variety plants recorded a weight of 115.87 g. The difference in average mass between the two lettuce varieties was 15.04 g and is not statistically significant (Table 2).

Table 2. The influence of lettuce varieties on the production of average mass (g)

Factor A	Average Mass (g))	Difference from Ct	Significance
a_1 Lugano	100.83	Ct	
a_2 Carmesi	115.87	15.04	FS

DL 5% 19.4 DL 1% 27.2 DL 0.1% 38.4

The effect of different cultivation technologies on the average mass of lettuce plants showed that in the case of natural oxygenation (b1), the average mass recorded was 82.02 g. The additional oxygenation variant (b2) resulted in an increase in production of 35.59 g compared to natural oxygenation (b1), statistically ensured as being highly significant.
Additional oxygenation plus LED lighting (b3) recorded a highly significant increase in production compared to natural oxygenation (b1), specifically 43.39 g (Table 3).

Table 3. The effect of different cultivation technologies on the average mass of lettuce plants

Factor B	Average Mass (g)	Difference from Ct	Significance
b_1 natural oxygenation	82.02	Ct	
b_2 additional oxygenation	117.61	35.59	***
b_3 additional oxygenation plus LED Light	125.41	43.39	***

DL 5% - 15.8
DL 1% - 22.2
DL 0.1% - 31.4

The impact of cultivation technologies on the average mass of Lugano and Carmesi lettuce plants showed that for the Lugano lettuce variety (a1) with natural oxygenation (b1), an average plant mass of 56.57 g was obtained. The additional oxygenation variant (b2) led to a highly significant increase in the average mass with a difference of 50.91 g compared to natural oxygenation, specifically 56.67 g. The variant with additional oxygenation plus LED lighting (b3) resulted in an even greater increase in the average mass to 124.57 g, with a difference of 68.01 g compared to natural oxygenation (b1). For the Carmesi variety (a2), natural oxygenation (b1) led to an average plant mass of 110.65 g. Additional oxygenation (b2) led to a highly significant increase in the average mass to 121.35 g, with a difference of 64.78 g compared to natural oxygenation (b1). The variant with additional oxygenation plus LED lighting (b3) resulted in an even greater increase in the average mass to 129.48 g, with a difference of 72.91 g compared to natural oxygenation (b1). These results indicate that the interaction between the lettuce variety and cultivation technology has a highly significant impact on the average mass of lettuce plants. Specifically, the addition of supplementary oxygenation and LED lighting is beneficial for increasing the average mass in both varieties, Lugano and Carmesi, leading to highly significant production increases (Table 4; Figure 3).

Table 4. The impact of cultivation technologies on the average mass of Lugano and Carmesi lettuce plants

Factor B	Factor A	Average Mass (g)	Diffe-rence from Ct	Signi-ficance
b_1 natural oxygenation	a_1 Lugano	56.57	Ct	
b_2 additional oxygenation	a_1 Lugano	107.47	50.91	***
b_3 additional oxygenation plus LED Light	a_1 Lugano	124.57	68.01	***
b_1 natural oxygenation	a_2 Carmesi	110.65	54.09	***
b_2 additional oxygenation	a_2 Carmesi	121.35	64.78	***
b_3 additional oxygenation plus LED Light	a_2 Carmesi	129.48	72.91	***

DL 5% - 15.8
DL 1% - 22.2
DL 0.1% - 31.4

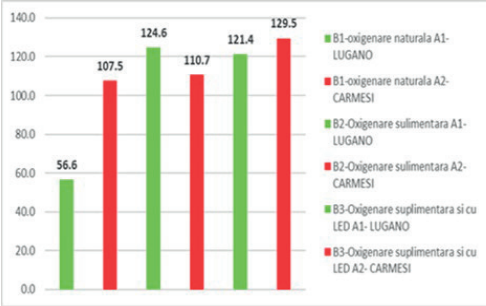

Figure 3. The impact of cultivation technologies on the average mass of Lugano and Carmesi lettuce plants

Root scanning was performed with an EPSON Flatbed Scanner Expression 11000X. For the Lugano lettuce variety (a1), the average root length was 34.47 cm, and for Carmesi, it was 35.51 cm (Figure 4).

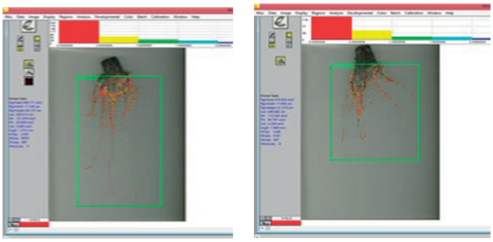

Figure 4. Root scanning of Lugano and Carmesi

The difference in root length between the two varieties is 1.04 cm, not statistically significant (Table 5).

Table 5. Morphometric analysis of root length for Lugano and Carmesi lettuce varieties

Factor A	Average Root Length (cm)	Difference from Ct	Significance
a_1Lugano	34.47	Ct	
a_2Carmesi	35.51	1.07	-

DL 5% - 8.7
DL 1% - 12.2
DL 0.1% - 17.2

Analyzing the morphometric results of the average root length of Lugano and Carmesi lettuce under different cultivation technologies, it was found that there are no significant differences depending on the cultivation technology used. The technology with additional oxygenation (b2) led to an increase in the average root length, with a difference of 3.92 cm compared to natural oxygenation (b1). The introduction of LED lighting along with additional oxygenation (b3) resulted in a difference of 1.85 cm compared to natural oxygenation (b1), but smaller than that observed in the case of additional oxygenation (b2) (Table 6).

Table 6. Morphometric analysis of the average root length of lettuce under different cultivation technologies

Factor B	Average Root Length (cm)	Difference from Ct	Significance
b_1 natural oxygenation	33.07	Ct	
b_2 additional oxygenation	36.98	3.92	-
b_3 additional oxygenation plus LED Light	34.92	1.85	-

DL 5% - 7.1
DL 1% - 9.9
DL 0.1% - 14.0

Analyzing the impact of cultivation technologies on the average root length in the case of lettuce varieties, it is observed that for the Lugano lettuce variety, additional oxygenation (b2) led to a significant increase in the average root length by 5.07 cm compared to natural oxygenation (b1). The introduction of LED lighting along with additional oxygenation (b3) resulted in an even greater increase in the average root length, with a difference of 8.00 cm compared to natural oxygenation (b1). For the Carmesi lettuce variety, natural oxygenation (b1) had an average root length of 35.43 cm, while additional oxygenation (b2) and additional oxygenation plus LED lighting (b3) showed an average root length smaller than natural oxygenation, with differences of 3.80 cm and 4.97 cm, respectively. These results indicate that the interaction between cultivation technologies and the cultivated variety can have a significant impact on the average root length.

Additional oxygenation appears to have a positive effect on root length in the case of the Lugano variety, while for the Carmesi variety, this technology may lead to a decrease in root length. The introduction of LED lighting appears to increase root length in both varieties, but to a greater extent in the case of the Lugano variety. It is important to consider these findings in the development and implementation of agricultural practices to maximize the production and quality of lettuce crops (Table 7; Figure 5).

Table 7. The impact of cultivation technologies on the average root length of Lugano and Carmesi lettuce varieties

Factor B	Factor A	Average Root Length (cm)	Difference from Ct	Significance
b_1 natural oxygenation	a_1 Lugano	30.53	Ct	
b_2 additional oxygenation	a_1 Lugano	35.60	5.07	***
b_3 additional oxygenation plus LED Light	a_1 Lugano	38.53	8.00	***
b_1 natural oxygenation	a_2 Carmesi	35.43	4.90	***
b_2 additional oxygenation	a_2 Carmesi	34.33	3.80	**
b_3 additional oxygenation plus LED Light	a_2 Carmesi	35.50	4.97	***

DL 5% - 2.49
DL 1% - 3.42
DL 0.1% - 4.68

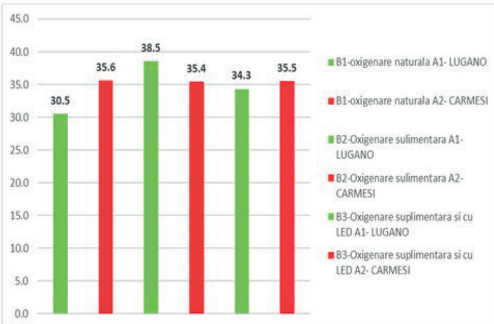

Figure 5. The impact of cultivation technologies on the average root length of Lugano and Carmesi lettuce varieties

The average root volume of the two lettuce varieties was also determined by scanning, with the following results: for the Lugano lettuce variety, the average root volume was 8.62 cm^3, while for the Carmesi lettuce variety, the average volume was 10.06 cm^3.

We observe a statistically insignificant difference between the two varieties, with an increase of 1.43 cm^3 in the average root volume for the Carmesi variety compared to Lugano (Table 8).

Table 8. Analysis of the average root volume of Lugano and Carmesi lettuce

Factor A	Average Root Volume (cm^3)	Difference from Ct	Significance
a_1Lugano	8.62	Ct	
a_2Carmesi	10.06	1.43	-

DL 5% - 1.82
DL 1% - 2.54
DL 0.1% - 3.60

Analyzing the average root volume for the two lettuce varieties, it is evident that with the natural oxygenation technology (b1), the average root volume was 7.25 cm^3. In the case of additional oxygenation (b2), the average root volume was 9.93 cm^3, with a significantly distinct difference of 2.68 cm^3 compared to the technology with natural oxygenation. In the variant with additional oxygenation plus LED light (b3), the average root volume was 10.83 cm^3, with a very significant difference of 3.58 cm^3 compared to technology b1. These results suggest that cultivation technologies involving additional oxygenation, especially when combined with LED light, can contribute to a significant or very significant increase in the average root volume. This is important in the context of growing and developing healthy plants in controlled cultivation systems (Table 9).

Table 9. Analysis of the average root volume of Lugano and Carmesi lettuce under different cultivation technologies

Factorul B	Average Root Volume (cm^3)	Difference from Ct	Significance
b_1 natural oxygenation	7.25	Ct	
b_2 additional oxygenation	9.93	2.68	**
b_3 additional oxygenation plus LED Light	10.83	3.58	***

DL 5% - 1.48
DL 1% - 2.08
DL 0.1% - 2.94

Analyzing the impact of cultivation technologies on the average root volume in the case of lettuce varieties, it is observed that for the Lugano lettuce variety with natural oxygenation (b1), the average root volume was 4.83 cm^3. The technology with additional oxygenation (b2) resulted in a significant increase in the average root volume to 9.67 cm^3, with a difference of 4.83 cm^3 compared to natural oxygenation. In the case of the technology with additional oxygenation plus LED light (b3), it produced a further increase in the average root volume to 10.20 cm^3, with a difference of 5.37 cm^3 compared to natural oxygenation. For the Carmesi lettuce variety in the variant with natural oxygenation (b1), the average root volume is recorded at 9.67 cm^3, the same as in the case of the Lugano variety. The variant with additional oxygenation (b2) resulted in a significant increase in the average root volume to 10.83 cm^3, with a difference of 6.00 cm^3 compared to natural oxygenation. For the technology with additional oxygenation plus LED light (b3), a similar increase in the average root volume was achieved. These results suggest that for both the Lugano and Carmesi lettuce varieties, additional oxygennation and especially its combination with LED lighting have a significant positive effect on the average root volume (Table 10).

Table 10. The impact of cultivation technologies on the root volume of Lugano and Carmesi lettuce varieties

Factor B	Factor A	Average Root Volume (cm^3)	Difference from Ct	Significance
b_1 natural oxygenation	a_1 Lugano	4.83	Ct	
b_2 additional oxygenation	a_1 Lugano	9.67	4.83	***
b_3 additional oxygenation plus LED Light	a_1 Lugano	10.20	5.37	***
b_1 natural oxygenation	a_2 Carmesi	9.67	4.83	***
b_2 additional oxygenation	a_2 Carmesi	10.83	6.00	***
b_3 additional oxygenation plus LED Light	a_2 Carmesi	10.83	6.00	***

DL 5% - 1.80
DL 1% - 2.47
DL 01 % - 3.38

The dissolved oxygen level (DO) was measured using a portable oxygen meter. We conducted measurements of the oxygen level at the inlet and outlet of the culture trough, accompanied by recording the temperature of the nutrient solution (Table 11).

Table 11. Oxygen consumption of plants in the nutrient

Factor B	Factor A	The amount of oxygen in the nutrient solution at the inlet mg/l	The amount of oxygen in the nutrient solution at the outlet mg/l	Inlet solution temperature °C	Outlet solution temperature °C
b_1 natural oxygenation	a_1 Lugano	4.8	3.1	21.6	21.7
b_2 additional oxygenation	a_1 Lugano	6.8	4.8	21.6	21.8
b_3 additional oxygenation plus LED Light	a_1 Lugano	8.2	5.2	21.8	21.8
b_1 natural oxygenation	a_2Carmesi	6	3.4	21.6	21.7
b_2 additional oxygenation	a_2Carmesi	7.7	4.5	21.6	21.8
b_3 additional oxygenation plus LED Light	a_2Carmesi	8.3	5.2	21.8	21.8

CONCLUSIONS

The Carmesi lettuce variety exhibits a higher average plant mass than the Lugano variety; however, the difference in weight is not statistically significant. This suggests that, regarding the average plant mass of lettuce, there is no clear difference between the two varieties. Cultivation technologies involving additional oxygenation, especially when combined with LED lighting, have a very significant positive effect on the average plant mass of lettuce. These technologies lead to significant increases in the average plant mass, both for the Lugano and Carmesi varieties. There are significant differences in the average root length depending on the cultivation technology used. The technology involving additional oxygenation, especially in combination with LED lighting, leads to significant increases in the average root length.

The impact of cultivation technologies varies depending on the lettuce variety. Additional oxygenation appears to have a positive effect on root length in the case of the Lugano variety but may result in a decrease in the case of the Carmesi variety.

Cultivation technologies involving additional oxygenation, especially when combined with LED lighting, significantly contribute to increasing the average volume of roots. This is crucial for the development of healthy plants in controlled cultivation systems. In conclusion, the proper selection and implementation of cultivation technologies can have a significant impact on the mass and development of lettuce plants. Additional oxygenation and LED lighting appear to be effective strategies for improving lettuce yield and quality, although the effects may vary depending on the lettuce variety and specific cultivation context.

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