Original scientific paper | DOI 10.7251/ZARS2401074T

Influence of two different types of fertilizer on baby leaf lettuce (*Lactuca sativa L.*) in a hydroponic system

Ivan Tupajić[1], Nenad Đurić[1], Vladimir Miladinović[1✉], Veselinka Zečević[1], Radiša Đorđević[1], Marija Bajagić[2], Milan Ugrinović[1]

[1] *Institute for Vegetable Crops, Smederevska Palanka, Serbia*
[2] *University Bijeljina, Faculty of Agriculture, Bijeljina, Republic of Srpska, B&H*

✉ vladimir.miladinovic33@gmail.com

Abstract

Lettuce (*Lactuca sativa* L.) is one of the most popular leafy vegetables used in human nutrition. Owing to its nutrient and mineral content, and high concentrations of vitamins and fibers, lettuce is considered as beneficial for human health. The short growing season makes lettuce convenient for growth in hydroponic systems. This paper aimed to study the effects of different mineral fertilizers on development and chlorophyll content in lettuce cultivated in controlled hydroponic systems. The research was carried out during January-February 2024 at the Institute for Vegetable Crops Smederevska Palanka, Serbia. The commercial lettuce cultivar "Jukebox" was cultivated for 30 days in a peat substrate, in a hydroponic system with artificial illumination. For lighting, light-emitting diodes (LEDs) were used. Plants were illuminated with multispectral white light (350-700 nm) at the temperature of 23 ± 2ºC and photoperiod of 8/16h (day/night). The experiment was set up in three replicates. The treatments were: Commercial fertilizer (CHF) intended for hydroponic production and soluble mineral fertilizer (SMF), applied in two different EC rates (1.5 and 2.5 mS/cm). For the first 15 days, the experiment was watered every day for 15 minutes, later watering was done twice a day for 15 minutes at intervals of ten hours. After 30 days of cultivation in a hydroponic system, growth parameters (fresh plant mass, above ground biomass and number of leaves) and chlorophyll content were measured. The CHF treatment significantly ($p \leq 0.01$) increased the mass of the plant (13.94g) comparing to SMF treatment (9.79g) The values of leaf chlorophyll content was significantly higher on the CHF treatment (26.43 SPAD) comparing to SMF treatment (22.18 SPAD) on the lower level of probability ($p \leq 0.05$). Nevertheless, the differences in mass and chlorophyll content indicate that the nutrients in CHF are better used compared to the SMF treatment especially at the 1.5 mS/cm EC level.

Key words: lettuce, fertilizer, treatments, hydroponic

INTRODUCTION

Lettuce is a very popular leafy vegetable that is widely grown and consumed all over the world. The significant content of vitamins, minerals and fibers make it very healthy, nutritious and desirable in the human diet (Morris et al., 2018). Furthermore, it is highly valued for its content of ascorbic acid (vitamin C) and occasionally for some genotypes, a group of phenolic compounds (anthocyanins) that influence the overall antioxidant activity of lettuce (Medina-Lozano et al., 2021). However, frequent consumption of lettuce can lead to health and safety problems because susceptibility to microbiological contamination, nitrate or heavy metals contamination which directly depends on the method of production (FDA 2006; Paradelo et al., 2020; Kappel et al., 2021; Ikkonen & Kaznina 2022; Bolivar et al., 2023). Lettuce was grown in the open field of temperate and moderately cold areas since the ancient times, but modern growing techniques are focused mainly on growing in greenhouses (Engindeniz and Tuzel 2006;

Ugrinović et al., 2011; Lebeda et al., 2022). Moreover, in recent years, cultivation in soiless substrates, as well as hydroponic systems, under artificial lighting has become more and more widespread. Modern research efforts are aimed at finding new cultivation techniques that would reduce water consumption and energy input, contamination and accumulation of polutants, but also production costs (Moreno-Perez et al., 2015; Miller et al., 2020; Ciriello et al., 2021; Majid et al., 2021; Lebeda et al., 2022; Wang et al., 2023).

Growing food in the hydroponics system gains importance when looking at global trends, population increase with a simultaneous decrease in agricultural production areas (Malouin et al., 2021). Such trends condition the transition to modern agrotechnology's food production systems and abandoning the traditional way of food production in soil and open field (Thomas et al., 2021). Due to the need to improve stability of food production, the Food and Agriculture Organization recommends production of food in soilless systems (hydroponics) in developing countries (Caputo et al., 2022). Some studies show that food production in the hydroponic system contributes to sustainable development, stability of food production with the profitability comparable traditional production on the soil with ecologically acceptable standards (Gumisiriza et al., 2022).

Hydroponics is a way of growing plants with roots immersed in mineral nutrients solution without using soil as a substrate (Raviv et al., 2019). It enables rational application of fertilizers and selective control of nutrient application, which allows the availability of useful nutrients to the plant and prevents the presence of harmful ones, such as nitrates and heavy metals in a larger amount than allowed (Novaes et al., 2009; Kappel et al., 2021; Ikkonen & Kaznina 2022; Bolivar et al., 2023).

According to the method of using the mineral solution, we have an open and a closed system of hydroponics. In an open system of hydroponics, part of the mineral solution is separated from the system and flows out while in a closed system, the solution is collected and continuously flows within the feed system and plant roots, without discharge (Voogt and Bar-Yosef, 2019). This situation in the hydroponic system gives the possibility to relatively easily influence the pH value, electrical conductivity, nutrient content, etc. (Richa et al., 2021).

Apart from the obvious advantages of hydroponic systems, there are also some negative aspects of its application. Hydroponics allows relatively high yield of vegetables on a small area with the saving of human labor, water and mineral nutrients while the only limiting factor is the initial cost of infrastructure. The whole systems consisted of water pumps, pipes and additional light are usually very expensive to establish (Gumisiriza et al., 2022). Furthermore, specialized commercial fertilizers are not cheap and sometime are not widely available (Alexander et al., 2023). Finally, during the last decade, the production of baby leaf lettuce is starting to gain more and more importance (Moraes et al 2016; Gimenez et al. 2020).

The aim of this work was to test the effects of commercial hydroponic and mineral fertilizer in different doses in order to examine possibility of usage of cheaper mineral fertilizer intended for fertirigation in order to replace expensive commercial hydroponic fertilizers.

MATERIALS AND METHODS

The experiment was set up in a modified hydroponic production system, in the protected area of the Institute for Vegetable crops Smederevska Palanka (102 m altitude, 44°22' north latitude, 20°47 east longitude). The commercial variety of lettuce (*Lattuca sativa* L. var. *capitata*) *Jukebox* (Vilmorin-Mikado, France) was sown in styrofoam containers filled with commercial substrate (Pindstrup Mosebrug A/S, Danmark). On the january 16^{th} 2024, plants were transplanted in the hydroponic pots filled with the same substrate and placed in the hydroponics consisted of NFT (nutrient film technique) plastic watertight channels with around 50 places for pots/m^2, whereby a very shallow stream of water containing examined fertilizers recirculated, one or two time a day (15 or 30 min/day) in a thin layer. Commercial fertilizer (CHF) intended for hydroponic production, Pro-Line HydroGrowth, (HESI Plantenvoeding B.V.), as well as a soluble mineral fertilizer (SMF), Solinure GT5 (ICL Group, Israel), which was alternative fertilizing treatment, were used. Nutrient content of examined fertilizers Based on preliminary tests and literature sources, the EC concentration was determined and maintained at a value of 1.5 mS in the watering solution. The entire system of reservoirs, pumps and channels were separated by treatments and repetitions. There were 30 l of solution in each tank. Electroconductivity was measured with a multimeter PC 700 (Eutech instruments) and the initial amount of mineral and commercial hydroponic fertilizer, determined during the preliminary tests were added (108.0 ml and 22.5 g /30 l, i.e. per tank). The experiment was set up in three replicates. During the experiment, the EC value of the solution was maintained at 1.5 mS and 2.5 mS for the second factor levels. For the first 15 days, the experiment was watered every day for 15 minutes, later watering was done twice a day for 15 minutes at intervals of ten hours (modified hydroponic/NFT system). Full Spectrum Model Q 100w LED diodes (350-700 nm spectrum) were used for lighting. Photo transition was 8/16 hours (day/night). The temperature in the protected area was maintained at 23 ± 3ºC.

After 30 days of setting up the experiment samples of 5 plants per repetition were collected. The mass of lettuce using a IoT-Line Precision Balance 572-31 technical scale (Kern & sohn GmbH, Germany), and the number of leaves (by counting) and the chlorophyll content was determined by Portable Chlorophyll Meter CM-8 and is expressed in SPAD units. The data colected has been processed by the method of analysis of variance using the SPSS program.

Table 1. Nutrients content (%) in tested fertilizers CHF (Commercial Hydroponic fertilizer) and SMF (Soluble mineral fertilizer)

Nutrient content	Fertilizer	
	CHF	SMF
Nitrogen (N)	6,3	19,62
Phosphorus (P_2O_5)	4,3	19,34
Potassium (K_2O)	5,4	20,87
Boron (B)	0,010	0,11
Copper (Cu)	0,002	0,0022
Iron (Fe)	0,020	0,36
Manganese (Mn)	0,010	0,009
Molybdenum (Mo)	0,001	0,0021
Zinc (Zn)	0,002	0,0022

RESULTS AND DISCUSSION

The average plant mass, fresh plant aboveground mass (baby leaves yield per plant) (kg/plant), number of leaves, and chlorophyll content varied on examined treatments, i.e. different fertilizers (CHF and SMF) as well as different concentrations (EC 1.5 and 2.5). Based on the results of the analysis (ANOVA), it can be concluded that the investigated factors significantly influenced the plant mass, the mass of the above ground fresh plant mass and the content of chlorophyll at both levels of probability ($p \leq 0.05$ and $p \leq 0.01$) while the number of leaves was influenced without significance (Table 2.).

Table 2. Mean squares (MS) of plant mass, above ground mas (baby leaves mass), number of leaves per plant, and chlorophyll content (SPAD)

	df	Plant mass	Above ground mass (baby leaf yield per plant)	Number of leaves	Chlorophyl content
Treatment	1	43.518**	40.117**	5.4^{ns}	210.188**
Concentration	1	152.085**	147.826**	38.4^{ns}	198.38**
T/C	1	254.692**	245.089**	9.6^{ns}	3.8^{ns}
Error	2	5.486	5.035	4.338	21.017

The highest average value of Plant mass was recorded using the lower EC value of CHF treatment (13.88g/plant), while the lowest average plant mass was recorded on the SHF EC 1.5 (g/plant), (Table 3.). The mass of the above-ground parts (baby leaves) was significantly affected by the type of fertilizer and its concentrations and the relations were the same as for the average plant mass which can indicate the possible correlation between traits (data not shown). The lowest mass of the aboveground plant partc (baby leaves) was recorded with a lower concentration of SMF fertilizer (9.46 g/plant), and the highest mass of the aboveground mass was recorded with the lower concentration of the CHV treatment (13.45 g/plant), (Table 3.). In terms of the number of leaves, there were no significant differences between the treatments. The lowest chlorophyl content was recorded on the SMF treatment with 1.5 EC (22.18) and the highest value of chlorophyl content was on the CHF treatment with 2.5 EC mass of the aboveground mass was recorded with the lower concentration of the CHV treatment (29.31).

Table 3. Average values of examined traits, number of leaves per plant, fresh plant weight (g), and chlorophyll content (SPAD) for two different traeatments

Treatment	Plant mass (g/plant)	Above ground mass (g/plant)	Number of leaves	Chlorophyl content (SPAD)
SMF (1.5)	9.79	9.46	20.27	22.18
SMF (2.5)	10.66	10.28	22.76	25.60
CHF (1.5)	13.88	13.45	20.63	26.45
CHF (2.5)	10.90	10.48	21.20	29.31
Average	11.31	10.92	21.22	25.89
Significance				
LSD 0.05	1.39	1.33	1.24	2.72
LSD 0.01	1.84	1.76	1.63	3.60

Except for the chlorophyll content, all other traits performed the highest values for the lower concentration of CHF treatment, while in several traits, the treatment SMF 2.5 showed almost similar results.

The nonsignificant difference between the number of leafs for the CHF and SMF treatments (on both concentrations) is in accordance with some other investigations (Andriolo et al., 2005; Ugrinovic et al., 2011) but opposite to result of Al-Tawaha et al. (2018). The number of lettuce leaves per plant depending on variety, environmental conditions such as light, temperature, available nutrients, etc. (Dalastra et al 2020; Lee et al., 2022; Alrajhi et al., 2023).

Within the trials concerning the different spacing between the plants and different EC concentrations (from 0.4 to 0.16 mS/cm), Calori et al. (2019) recorded the values of fresh leaves per plant from 7.75 to 12.25g., which is comparable to our results having in mind the differences in plant density. This is also in accordance with another recent study concerning the different amounts of nutrients per plant (Lee et al., 2022).

Different types and amounts of fertilizers as well as different ratio of nutrients in the fertilizers cause variations in lettuce fresh weight values (Sublett et al., 2018; Frasetya et al., 2021). Higher fresh lettuce weight per plant on CHF treatment can be related to higher content of nitrogen and some other rnutrients in the CHF solution as well as presence of some helated microelements (Table 1), having in mind the amount of applied fertilizers.

However, the additional N fertilization does not increase the chlorophyll content (Qadir et al., 2017). The possibility that the increase in chlorophyll was decisively influenced not only by the appropriate content of macro and microelements, but also by their exact ratio should not be excluded.

CONCLUSION

The absence of a difference in the number of leaves between the treatments shows that the tested SMF fertilizer has all the micro and macro elements necessary to reach the appropriate stage of lettuce development. Nevertheless, the differences in mass and chlorophyll content indicate that the nutrients in CHF are more available i.e. better used compared to the SMF treatment, regardless of whether it is a question of a greater amount of certain nutrients or a better balance of nutrients in CHF. For the successful use of an alternative SMF, it would be necessary to add some more fertilizers with differently balanced nutrients or to change the EC values. Considering that higher doses of CHF showed a depressing effect on the examined parameters, a higher EC concentration than 2 mS/cm should not be applied.

ACKNOWLEDGEMENTS

The research team owes a great debt of gratitude to the Ministry of Agriculture, Forestry and Water Management, as well as the parent Ministry of Science, Technological Development and Innovation of the Republic of Serbia, which enabled the realization of this work with institutional funding (No 451-03-66/2024-03/200216)

REFERENCES

Alexander, P., Arneth, A., Henry, R., Maire, J., Rabin, S., & Rounsevell, M.D. (2023). High energy and fertilizer prices are more damaging than food export curtailment from Ukraine and Russia for food prices, health and the environment. *Nature Food*, 4(1), 84-95. DOI: 10.1038/s43016-022-00659-9

Al-Tawaha, A.R., Al-Karaki, G., Al-Tawaha, A.R., Sirajuddin, S.N., Makhadmeh, I., Megat Wahab, P.E., & Massadeh, A. (2018). Effect of water flow rate on quantity and quality of lettuce (Lactuca sativa L.) in nutrient film technique (NFT) under hydroponics conditions. *Bulgarian Journal of Agricultural Science*, 24(5), 793-800.

Alrajhi, A.A., Alsahli, A.S., Alhelal, I.M., Rihan, H.Z., Fuller, M.P., Alsadon, A.A., & Ibrahim, A.A. (2023). The effect of LED light spectra on the growth, yield and nutritional value of red and green lettuce (*Lactuca sativa*). *Plants*, 12(3), 463. DOI: 10.3390/plants12030463

Andriolo, J.L., Luz, G.L.D., Witter, M.H., Godoi, R.D.S., Barros, G.T., & Bortolotto, O.C. (2005). Growth and yield of lettuce plants under salinity. *Horticultura Brasileira*, 23, 931-934. DOI: https://doi.org/10.1590/S0102-05362005000400014

Bolivar, A., Saiz-Abajo, M. J., Garcia-Gimeno, R. M., Petri-Ortega, E., Diez-Leturia, M., Gonzalez, D., & Perez-Rodriguez, F. (2023). Cross contamination of Escherichia coli O157: H7 in fresh-cut leafy vegetables: Derivation of a food safety objective and other risk management metrics. *Food Control*, 147, 109599. DOI: 10.1016/j.fm.2014.08.025

Calori, A.H., Purquerio, L.F.V., Factor, T.L., Júnior, S.L., & Moraes, L.A.S. (2019). Effects of electric conductivity and plant density on lettuce baby leaf production in NFT hydroponic system. *Acta Horticulturae*, 1249, 5-10. DOI: https://doi.org/10.17660/ActaHortic.2019.1249.2

Caputo, S. (2022). History, techniques and technologies of soil-less cultivation. *Small Scale Soil-less Urban Agriculture in Europe*, 45-86. DOI: 10.1007/978-3-030-99962-9_4

Ciriello, M., Formisano, L., Pannico, A., El-Nakhel, C., Fascella, G., Duri, L. G., & Carillo, P. (2021). Nutrient solution deprivation as a tool to improve hydroponics sustainability: Yield, physiological, and qualitative response of lettuce. *Agronomy*, 11(8), 1469**.** DOI: https://doi.org/10.3390/agronomy11081469

Dalastra, C., Teixeira Filho, M., da Silva, M.R., Nogueira, T.A., & Fernandes, G.C. (2020). Head lettuce production and nutrition in relation to nutrient solution flow. *Horticultura Brasileira*, 38, 21-26. DOI: 10.1590/S0102-053620200103

Engindeniz, S., & Tuzel, Y. (2006). Economic analysis of organic greenhouse lettuce production in Turkey. *Scientia Agricola*, 63, 285-290. DOI: https://doi.org/10.1590/S0103-90162006000300012

Frasetya, B., Harisman, K., & Ramdaniah, N.A.H. (2021). The effect of hydroponics systems on the growth of lettuce. In IOP Conference Series: *Materials Science and Engineering*, 1098(4), 042115. DOI: 10.1088/1757-899X/1098/4/042115

FDA. Commodity Specific Food Safety Guidelines for the Lettuce and Leafy Greens Supply Chain 1st Edition. Available online: https://www.fda.gov/media/77279/download (accessed on 13

Gimenez, A., Fernández, J.A., Pascual, J.A., Ros, M., & Egea-Gilabert, C. (2020). Application of directly brewed compost extract improves yield and quality in baby leaf lettuce grown hydroponically. Agronomy, 10(3), 370. DOI: https://doi.org/10.3390/agronomy10030370

Gumisiriza, M.S., Ndakidemi, P., Nalunga, A., & Mbega, E.R. (2022). Building sustainable societies through vertical soilless farming: A cost-effectiveness analysis on a small-scale non-greenhouse hydroponic system. *Sustainable Cities and Society*, 83, 103923. DOI: 10.1016/j.scs.2022.103923

Gumisiriza, M.S., Ndakidemi, P.A., & Mbega, E.R. (2022). A simplified non-greenhouse hydroponic system for small-scale soilless urban vegetable farming. *MethodsX*, 9, 101882. DOI: https://doi.org/10.1016/j.mex.2022.101882

Ikkonen, E., & Kaznina, N. (2022). Physiological responses of lettuce (*Lactuca sativa* L.) to soil contamination with Pb. *Horticulturae* 2022, 8, 951. DOI: https://doi.org/10.3390/horticulturae8100951

Kappel, N., Boros, I.F., Ravelombola, F.S., & Sipos, L. (2021). EC sensitivity of hydroponically-grown lettuce (Lactuca sativa L.) types in terms of nitrate accumulation. *Agriculture*, 11(4), 315. DOI: https://doi.org/10.3390/agriculture11040315

Lee, J. S., Chandra, D., & Son, J. (2022). Growth, physicochemical, nutritional, and postharvest qualities of leaf lettuce (*Lactuca sativa* L.) as affected by cultivar and amount of applied nutrient solution. *Horticulturae*, 8(5), 436. DOI: https://doi.org/10.3390/horticulturae8050436

Lebeda, A., Křístková, E., Kitner, M., Widrlechner, M. P., Maras, M., & El-Esawi, M.A. (2022). Egypt as one of the centers of lettuce domestication: morphological and genetic evidence. *Euphytica*, 218, 10. DOI: 10.1007/s10681-021-02960-3

Majid, M., Khan, J.N., Shah, Q.M.A., Masoodi, K.Z., Afroza, B., & Parvaze, S. (2021). Evaluation of hydroponic systems for the cultivation of Lettuce (*Lactuca sativa* L., var. *Longifolia*) and comparison with protected soil-based cultivation. *Agricultural Water Management*, 245, 106572. DOI: 10.1016/j.agwat.2020.106572

Medina-Lozano, I., Bertolín, J. R., & Díaz, A. (2021). Nutritional value of commercial and traditional lettuce (*Lactuca sativa* L.) and wild relatives: Vitamin C and anthocyanin content. *Food Chemistry*, 359, 129864. DOI: https://doi.org/10.1016/j.foodchem.2021.129864

Miller, A., Langenhoven, P., & Nemali, K. (2020). Maximizing productivity of greenhouse-grown hydroponic lettuce during winter. *HortScience*, 55(12), 1963-1969. DOI: https://doi.org/10.21273/HORTSCI15351-20

Moraes, L.A., Calori, A.H., Factor, T.L., Patrício, F.R., Ghini, R., Abreu, M.F., & Purquerio, L.F. (2016). Baby leaf lettuce production in trays with reused and solarized substrate. *Horticultura Brasileira*, 34, 463-469. DOI: https://doi.org/10.1590/S0102-053620160403

Moreno-Perez, E.D.C., Castillo, S.D., Gutierrez-Tlaque, J., Gonzalez-Molina, L., Pineda-Pineda, J. (2015). Greenhouse lettuce production with and without nutrient solution recycling. *Revista Chapingo. Serie Horticultura*, 21(1), 43-55. DOI: https://doi.org/10.5154/r.rchsh.2013.12.047

Morris, M.C., Wang, Y., Barnes, L.L., Bennett, D.A., Dawson-Hughes, B., & Booth, S.L. (2018). Nutrients and bioactives in green leafy vegetables and cognitive decline: Prospective study. *Neurology*, 90(3), 214-222. DOI: 10.1212/WNL.0000000000004815

Novaes, H.B., Vaitsman, D.S., Dutra, P.B., & Pérez, D.V. (2009). Determination of nitrate in lettuce by ion chromatography after microwave water extraction. *Quimica Nova, 32*, 1647-1650. DOI: 10.1590/S0100-40422009000600049

Paradelo, R., Villada, A., & Barral, M.T. (2020). Heavy metal uptake of lettuce and ryegrass from urban waste composts. *International Journal of Environmental Research and Public Health*, 17(8), 2887. DOI: https://doi.org/10.3390/ijerph17082887

Qadir, O., Siervo, M., Seal, C.J., & Brandt, K. (2017). Manipulation of contents of nitrate, phenolic acids, chlorophylls, and carotenoids in lettuce (*Lactuca sativa* L.) via contrasting responses to nitrogen fertilizer when grown in a controlled environment. *Journal of Agricultural and Food Chemistry*, 65(46), 10003-10010. DOI: 10.1021/acs.jafc.7b03675

Raviv, M., Lieth, J.H., & Bar-Tal, A. (2019). Significance of soilless culture in agriculture. In: Soilless Culture: Theory and Practice; Academic Press: Cambridge, USA; Elsevier: London, UK, pp. 3–14.

Richa, A., Fizir, M., & Touil, S. (2021). Advanced monitoring of hydroponic solutions using ion-selective electrodes and the internet of things: a review. *Environmental Chemistry Letters*, 19(4), 3445-3463. DOI: 10.1007/s10311-021-01233-8

Sublett, W.L., Barickman, T.C., & Sams, C.E. (2018). The effect of environment and nutrients on hydroponic lettuce yield, quality, and phytonutrients. *Horticulturae,* 4(4), 48. DOI: https://doi.org/10.3390/horticulturae4040048

Thomas, T., Biradar, M.S., Chimmad, V.P., & Janagoudar, B.S. (2021). Growth and physiology of lettuce (Lactuca sativa L.) cultivars under different growing systems. *Plant Physiology Reports,* 26(3), 526-534. DOI: 10.1007/s40502-021-00591-3

Ugrinović, M., Oljača, S., Brdar-Jokanović, M., Zdravković, J., Girek, Z., & Zdravković, M. (2011). The effect of liquid and soluble fertilizers on lettuce yield. *Savremena poljoprivreda,* 60(1-2), 110-115.

Voogt, W., & Bar-Yosef, B. (2019). Water and nutrients management and crops response to nutrient solution recycling in soilless growing systems in greenhouses. In: Soilless Culture: Theory and Practice; Raviv, M., Lieth, J.H., Bar-Tal, A., Eds.; Academic Press: Cambridge. DOI: https://doi.org/10.1016/B978-0-444-63696-6.00010-4

Wang, L., Ning, S., Zheng, W., & Ben-Gal A. (2023). Performance analysis of two typical greenhouse lettuce production systems: commercial hydroponic production and traditional soil cultivation. *Frontiers in Plant Science,* 14, 1165856. DOI: https://doi.org/10.3389/fpls.2023.1165856