Photosynthesis: Measuring The Effect Of Light Intensity And Carbon Dioxide Concentration On The Leaf Surface Area Of Eruca Sativa

Introduction

Photosynthesis is the chemical pathway by which plants use carbon dioxide (CO2), water and light to produce carbohydrates required as nutrients to allow for growth (Tanaka & Makino 2009).

With the impeding effects of climate change the balance of agricultural ecosystems is subject to interruption as increases in atmospheric CO2 are ubiquitous (Mladin et al. 2014). As industrialization continues to develop, atmospheric CO2 concentrations are rapidly increasing. The 2019 peak value was 3.5 ppm higher than the 411.2 ppm in 2018 with an average growth rate of 2.2 ppm per year within the last decade (Tans & Keeling 2019). An increase in CO2 concentration can benefit plants as they adapt by improving photosynthetic efficiency, changing structure and leaf surface properties (Chitarra et al. 2015). This was pronounced as studies on C(3) photosynthetic plants suggested that the doubling of atmospheric CO2 concentrations would increase plant growth and productivity by 30-50% (Kirschbaum 2004). Another study conducted on grapevines concluded that when exposed to elevated CO2 (700 ppm) the plant photosynthetic system acclimated to the environmental change (Salazar-Parra et al. 2015).

Furthermore, with an increase of sunlight in the last century the depletion of the ozone layer has been linked to an increase in light intensity (Kerr & McElroy 1993). Numerous studies highlighted that for some plants a decrease in light intensity may result in a modified leaf morphology, with smaller and thinner leaves compared to those exposed to a higher light intensity (Feng et al. 2019). The physiological adaptations developed as a result of increasing light intensity lead to an increase in photosynthetic capacity (Yang et al. 2014). Feng et al. determined that the leaf structure and anatomy was enhanced as soybeans were exposed to higher light intensities significantly increasing the photosynthetic rate.

Several researchers have examined photosynthetic capacity as a method to increase the growth of plants under different environmental conditions. However, its current understanding is quite limited, specifically under abiotic stress factors. Abiotic stress factors that can impact the rate of photosynthesis in plants include increasing or limiting CO2 concentration and light intensity (Mladin et al. 2014). However, “the light intensity at which the photosynthetic system becomes light saturated increases with increasing CO2 concentration and vice versa” (WILSON & COOPER 1969).

Eruca sativa is a C(3) herbaceous oilseed plant from the Brassicaceae family (Gajra Garg & Vinay Sharma 2014). It has the ability to grow in lands of poor fertility with in a vast range of environmental conditions including light intensity and CO2 concentration (Bakhshandeh et al. 2019). Therefore, it is an important commercial and industrial crop cultivated as a culinary condiment in salads, for its medicinal properties and for its quality of protein and seed oil.

In this current study it is hypothesised that if E. sativa is exposed to high light intensity (800 and elevated CO2 concentrations (1000 ppm), it will have the largest average leaf surface area as photosynthetic rate will increase. This is significant as it provides evidence for the suggested potential of E. sativa as a reliable future vegetation crop. It may also be considered a potential industrial oil crop to be exploited once fossil fuels are depleted as E. sativa oil is rich in erucic acid (Yankun Wang et al. 2014). This study will assist in bridging the gaps regarding the efficacy of E. sativa growth in extreme environmental conditions as the study tests the mean leaf surface area under elevated CO2 concentration levels with high light intensity (n= 100) or low light intensity (n=100) and ambient CO2 concentrations with high light intensity (n=100) in a Controlled Environment Facility with constant nutrients and water supply. Moreover, the study focuses on only two environmental limiting factors on the specific E. sativa plant.

Results

The sample size of this study was n = 100 E. sativa plants for each treatment. The mean leaf surface area (cm2) for E. sativa exposed to elevated CO2 concentration levels with high light intensity was 48.60 ± 1.02 cm2 while low light intensity was 33.32 ± 1.06 cm2 (Figure 1). The two-tailed t-tests concluded that there was a significant difference between the mean leaf surface area (cm2) of the two treatments as p

The mean leaf surface area (cm2) for E. sativa exposed to high light intensity with elevated CO2 concentration was 48.60 ± 1.02 cm2 while ambient CO2 concentration was 40.29 ± 1.16 cm2 (Figure 2). The two-tailed t-tests concluded that there is a significant difference between the mean leaf surface area (cm2) of the two treatments as p

Figure 1. The effect of light intensity (on E. sativa leaf surface area (cm2) for plants exposed to elevated concentration (1000 ppm) with high light intensity (800 (n=100) or low light intensity (200 (n=100). Error bars represents standard error.

Figure 2. The effect of concentration on E. sativa leaf surface area (cm2) for plants exposed to high light intensity (800 and with ambient (n=100) or with elevated (n=100). Error bars represents standard error.

Discussion

E. sativa exhibited a positive response when exposed to high light intensity and elevated CO2 concentrations. Their leaves had a significantly larger mean surface area (cm2) compared to those placed in environments of high light intensity with ambient CO2 and low light intensity with elevated CO2, therefore supporting the hypothesis (Figure 1 & 2). This provides evidence that E. sativa adapted efficiently in excess light intensity and CO2 concentrations. The average leaf surface area was larger when more CO2 and light was available, suggesting that the increased growth was a result of higher photosynthetic capacity(WILSON & COOPER 1969). This can be explained as photosynthesis consists of 2 separate stages. The first stage is the light dependent electron transport chain which requires chlorophyll pigment to absorb photons from light. The higher the light intensity the more photons per unit of time absorbed. The second stage is the light independent Calvin Cycle whereby in C(3) plants such as E. sativa, an increased atmospheric CO2 concentration absorbed through the stomata increases sugar production used as nutrients for growth (Harbinson & Hedley 1993). While these mechanisms may explain the

results produced, the indefinite understanding of the relationship between leaf surface area and photosynthesis is inconclusive. This is because it may be limited by other abiotic parameters including temperature, soil water and humidity as well as biotic factors such as insect pests and Fusarium Wilt which may impact disease prevalence (Chitarra et al. 2015).

Additionally, the study by Ainsworth et al. demonstrated that soybeans exposed to elevated CO2 concentrations (689 ppm) had a 39% leaf growth with an increase in photosynthetic rate. According to Pritchard et al. 66% of studies concluded that plants exposed to elevated CO2 concentrations had increased leaf area. Meanwhile, the findings of Wu, Gong & Yang suggested that when the soybean was in shade leaf expansion stopped while the total leaf area in full sunlight was significantly larger. While a study on Fragaria vesca, found that with increasing light intensity, leaf thickness, leaf density, and mesophyll cell surface area and volume per leaf surface area increased (Chabot & Chabot 1977). Similarly, a study on Helianthits anmius L. suggested that photosynthesis increased with increasing light intensity (2000-5500 ft-candles) and CO2 concentrations (115-400 ppm), however light intensities below 2000 ft-candles, limited the response. This is because as the light intensity decreased it inhibited the stomatal opening therefore limiting the CO2 absorbed. (WHITEMAN & KOLLER 1967)

Conversely, studies have demonstrated that elevated CO2 concentrations (800-850 ppm) had lower photosynthetic efficiency compared to CO2 at 450 ppm (Chitarra et al. 2015). Furthermore, according to a review by Pritchard et al., 6% of studies determined that plants grown in elevated CO2 concentrations decreased whole plant leaf area. While, Mousseau deduced that Castanea sativa Mill exposed to elevated CO2 (700 µmol·mol?1) had leaf areas that were either reduced or unchanged.

A cross analysis of the studies reveals that discrepancies may be due to varying plant types, methods and form of measurements used. However, there are not enough studies related to E. sativa and the effect of light intensity to enable direct comparison of results.

Furthermore, it must be considered that the results of the current study may have been more accurate if the limitations were avoided as the study did not account for a wide range of variables that may have influenced the results. For example, the plant subjects were E. sativa seedlings with varying unknown genotypic characteristics that may be projected differently in the phenotype of the plants in response to CO2 and light intensity. Therefore, a proposed improvement may be the creation of E. sativa clones to ensure all genetic differences are eliminated (WILSON & COOPER 1969). Moreover, although the controlled environments on Camden campus allowed for the manipulation of environmental conditions with different treatments to help understand the effect of Climate Change and the ozone layer depletion on E. sativa they cannot accurately replicate future ambient environment conditions. For example, fluctuating seasonal and daily temperatures, humidity, wind speed and UV radiation exposure as well as dynamic changes within the ecosystem, with competing plant life, altered number of fauna and disease prevalence (Mousseau 1993). Additionally, studies have suggested that mix-LED lamps are a better light source for photosynthesis compared to metal halide lamps which were utilised in this experiment and have a low red light output (Ren et al. 2018; Wei et al. 2019)

In conclusion the study supports the hypothesis, whereby the elevated CO2 and high light intensity allowed E. sativa leaves to have the largest mean surface area. This suggests that

photosynthetic capacity of E. sativa was also increased on a molecular level. Thus, providing evidence to support the use of E. sativa as a future vegetation crop and source of nutrients as it may withstand the modelled effects of climate change. However, additional research must be conducted to further support the conclusions given the inconsistencies in the literature. Given that atmospheric CO2 and ozone levels are already changing their effect on our crops and ecosystems is important to understand.

References

1. Ainsworth, E, Davey, P, Bernacchi, C, Dermody, O, Heaton, E, Moore, D, Morgan, P, Naidu, S, Ra, H-s, Zhu, X-g, Curtis, P & Long, S 2002, 'A meta-analysis of elevated [CO2] effects on soybean (Glycine max) physiologY', Global Change Biology - GLOB CHANGE BIOL, vol. 8, pp. 695-709.
2. Bakhshandeh, E, Pirdashti, H, Vahabinia, F & Gholamhossieni, M 2019, 'Quantification of the Effect of Environmental Factors on Seed Germination and Seedling Growth of Eruca (Eruca sativa) Using Mathematical Models', Journal of Plant Growth Regulation.
3. Chabot, BF & Chabot, JF 1977, 'Effects of light and temperature on leaf anatomy and photosynthesis in Fragaria vesca', Oecologia, vol. 26, no. 4, pp. 363-77.
4. Chitarra, W, Siciliano, I, Ferrocino, I, Gullino, ML & Garibaldi, A 2015, 'Effect of Elevated Atmospheric CO2 and Temperature on the Disease Severity of Rocket Plants Caused by Fusarium Wilt under Phytotron Conditions', PLoS ONE, vol. 10, no. 10, p. e0140769.
5. Feng, L, Raza, MA, Li, Z, Chen, Y, Khalid, MHB, Du, J, Liu, W, Wu, X, Song, C, Yu, L, Zhang, Z, Yuan, S, Yang, W & Yang, F 2019, 'The Influence of Light Intensity and Leaf Movement on Photosynthesis Characteristics and Carbon Balance of Soybean', Frontiers in Plant Science, vol. 9, no. 1952.
6. Gajra Garg & Vinay Sharma 2014, 'Eruca sativa (L.): Botanical Description, Crop Improvement, and Medicinal Properties', Journal of Herbs, Spices & Medicinal Plants, vol. 20, no. 2, pp. 171-82.
7. Harbinson, J & Hedley, CL 1993, 'Changes in P-700 Oxidation during the Early Stages of the Induction of Photosynthesis', Plant Physiology, vol. 103, no. 2, pp. 649-60.
8. Kerr, JB & McElroy, CT 1993, 'Evidence for Large Upward Trends of Ultraviolet-B Radiation Linked to Ozone Depletion', Science, vol. 262, no. 5136, pp. 1032-4.
9. Kirschbaum, MUF 2004, 'Direct and Indirect Climate Change Effects on Photosynthesis and Transpiration', Plant Biology, vol. 6, no. 3, pp. 242-53.
10. Mladin, L, Prodan, N, Grec, A & Cosmin, S 2014, ' THE EFFECT OF UVB STRESS ON PHOTOSYNTHESIS IN ERUCA SATIVA', Studia Universitatis ‘Vasile Goldis’ Arad. Seria Stiintele Vietii (Life Sciences Series), vol. 24, no. 3, pp. 329–31.
11. Mousseau, M 1993, 'Effects of elevated CO2 on growth, photosynthesis and respiration of sweet chestnut (Castanea sativa Mill.)', Vegetatio, vol. 104, no. 1, pp. 413-9.
12. Pritchard, SG, Rogers, HH, Prior, SA & Peterson, CM 1999, 'Elevated CO2 and plant structure: a review', Global Change Biology, vol. 5, no. 7, pp. 807-37.
13. Ren, X, Liu, Y, Jeong, HK & Jeong, BR 2018, 'Supplementary Light Source Affects the Growth and Development of Codonopsis lanceolata Seedlings', International journal of molecular sciences, vol. 19, no. 10, p. 3074.
14. Salazar-Parra, C, Aranjuelo, I, Pascual, I, Erice, G, Sanz-Sáez, Á, Aguirreolea, J, Sánchez-Díaz, M, Irigoyen, JJ, Araus, JL & Morales, F 2015, 'Carbon balance, partitioning and photosynthetic acclimation in fruit-bearing grapevine (Vitis vinifera L. cv. Tempranillo) grown under simulated climate change (elevated CO2, elevated

temperature and moderate drought) scenarios in temperature gradient greenhouses', Journal of Plant Physiology, vol. 174, pp. 97-109.
15. Tanaka, A & Makino, A 2009, 'Photosynthetic Research in Plant Science', Plant and Cell Physiology, vol. 50, no. 4, pp. 681-3.
16. Tans, P & Keeling, R 2019, Trends in Atmospheric Carbon Dioxide, viewed 17/09 2019, .
17. Wei, H, Zhao, J, Hu, J & Jeong, BR 2019, 'Effect of Supplementary Light Intensity on Quality of Grafted Tomato Seedlings and Expression of Two Photosynthetic Genes and Proteins', Agronomy, vol. 9, no. 6, p. 339.
18. WHITEMAN, PC & KOLLER, D 1967, 'INTERACTIONS OF CARBON DIOXIDE CONCENTRATION, LIGHT INTENSITY AND TEMPERATURE ON PLANT RESISTANCES TO WATER VAPOUR AND CARBON DIOXIDE DIFFUSION', New Phytologist, vol. 66, no. 3, pp. 463-73.
19. WILSON, D & COOPER, JP 1969, 'EFFECT OF LIGHT INTENSITY AND CO^2 ON APPARENT PHOTOSYNTHESIS AND ITS RELATIONSHIP WITH LEAF ANATOMY IN GENOTYPES OF LOLIUM PERENNE L.', New Phytol., vol. 68 pp. 627-44.
20. Wu, Y, Gong, W & Yang, W 2017, 'Shade Inhibits Leaf Size by Controlling Cell Proliferation and Enlargement in Soybean', Scientific Reports, vol. 7, no. 1, p. 9259.
21. Yang, F, Huang, S, Gao, R, Liu, W, Yong, T, Wang, X, Wu, X & Yang, W 2014, 'Growth of soybean seedlings in relay strip intercropping systems in relation to light quantity and red:far-red ratio', Field Crops Research, vol. 155, pp. 245-53.
22. Yankun Wang, Pu Chu, Qing Yang, Shengxin Chang, Jianmei Chen, Maolong Hu & Guan, R 2014, 'Complete Mitochondrial Genome of Eruca sativa Mill. (Garden Rocket)', PLoS ONE, vol. 9, no. 8.