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APPLICATION OF THE ACOUSTICS USING LASER TECHNOLOGY IN THE EVALUATION OF THE BIOLOGICAL SAMPLES RESPIRATION

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Abstract: *Cadmium (Cd) is a heavy metal (HM) that presents a great environmental problem due to its high toxicity to all living organisms. The aim of our study was to monitor the ammonia (NH_3), ethylene (C_2H_4), ethanol (C_2H_5OH) and carbon dioxide (CO_2) biomolecules emissions in Triticum aestivum plantlets growth with or without Cd, using photoacoustic spectroscopy in order to suggest new markers that may contribute to a better understanding of Cd phytotoxicity. Laser photoacoustic spectroscopy results show that seeds germinated with Cd, determine a slowly increase of NH_3 vapors in the respiration of plantlets, a decrease of C_2H_4, and a greater increase of C_2H_5OH and CO_2 vapors in the respiration of Triticum aestivum.*

Keywords: *photoacoustic spectroscopy, acoustics, biomolecules, heavy metal*

1. INTRODUCTION

Heavy metals are naturally occurring metallic elements with a higher density than water, higher than 5 g/cm^3 [1]. A part of these metals (Fe, Mn, Zn, Co, Cu and Ni) are macro- and micronutrients necessary in metabolic processes related to plant growth and so, can be removed, to some extent, from soil, through phytoextraction [1,2]. Other, such as Cd, Cr, Pb and Hg don't have any known biological function and additionally can become toxic to the plants at higher concentrations [2]. There are several sources of heavy metals in the environment which originate either from natural processes (volcanic eruptions, rock weathering, and soil forming processes) or anthropogenic processes.

However, the latter is the most alarming. Due to recent human activities, such as mining, industrial processing and use, agricultural practices, etc. it was reported an increase of environmental contamination which in the end means a higher toxicity to humans [3-5].

The purpose of this research was to investigate the effect of Cd on *Triticum aestivum* by monitoring the different volatile organic compounds- VOCs (NH_3, C_2H_4, C_2H_5OH, and CO_2) emitted by the plantlets under stress conditions.

2. TECHNICAL REQUIREMENTS

The CO_2 laser photoacoustic spectroscopy set-up used for the determination of the NH_3, C_2H_4, C_2H_5OH and CO_2 molecules is presented in Fig. 1 and extensively described in previous papers [6-10].

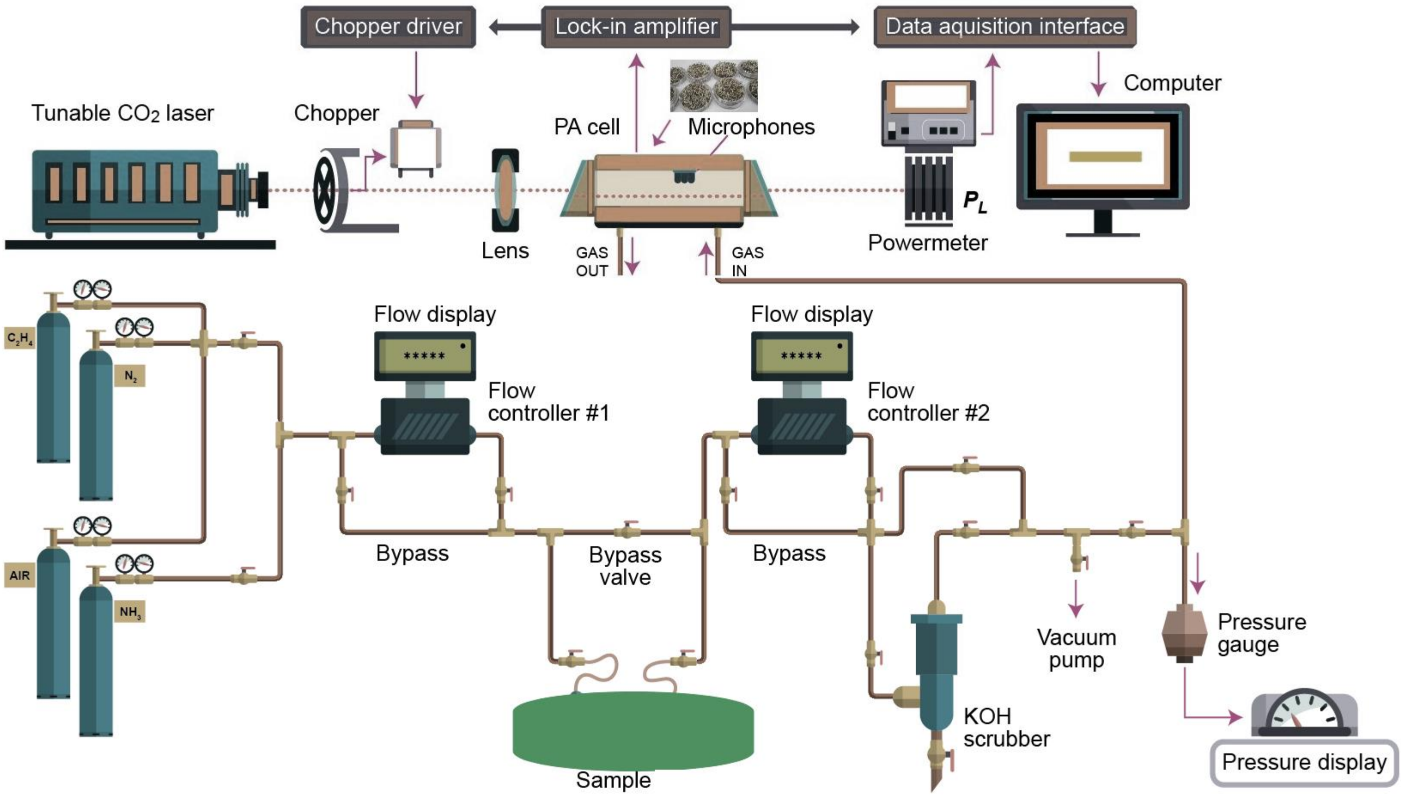

Figure 1: Photoacoustic CO_2 laser photoacoustic spectroscopy set-up used for the determination of the NH_3, C_2H_4, C_2H_5OH and CO_2 molecules

The laser photoacoustic spectroscopy detection set-up consists of a tunable continuously wave (CW) frequency stabilized CO_2 laser, emitting radiation in the 9.2–10.8 μm region on different vibrational-rotational lines, with a maximum power of 6.5 W, a lens system, a chopper, a photoacoustic cell, a powermeter, a lock-in amplifier, an acquisition board and a computer for data acquisition and processing. The acoustic detection chain is accompanied by a complex gas handling system built for a proper manipulation of the gases molecules under study, from the gas bottle to the photoacoustic cell.

The calibration measurements performed using commercially prepared, certified gas mixtures were reported previously [6-11].

The absorption coefficients of NH_3, C_2H_4, C_2H_5OH and CO_2 at different CO_2 laser wavelengths were precisely measured previously [10, 11] and the CO_2 laser was kept tuned at the 10.53 μm where C_2H_4 exhibit a strong peak, corresponding to an absorption coefficient of $30.4\ cm^{-1}atm^{-1}$ and at 9.22 μm, where the NH_3 absorption coefficient has the maximum value of $57\ cm^{-1}atm^{-1}$, at the 9.258 μm where C_2H_5OH exhibit a strong peak, corresponding to an absorption coefficient of $4.08\ cm^{-1}atm^{-1}$ and at the 9.533 μm where CO_2 exhibit a strong peak, corresponding to an absorption coefficient of $0.00301\ cm^{-1}atm^{-1}$.

Ammonia, C_2H_4, C_2H_5OH and CO_2 molecules generated by the samples were measured at 80 h from the germination of the *Triticum aestivum* seeds in water or in the presence of Cd.

Figure 2 shows the level of the VOCs emitted by *Triticum aestivum* seeds after 80 h of germination with or without Cd.

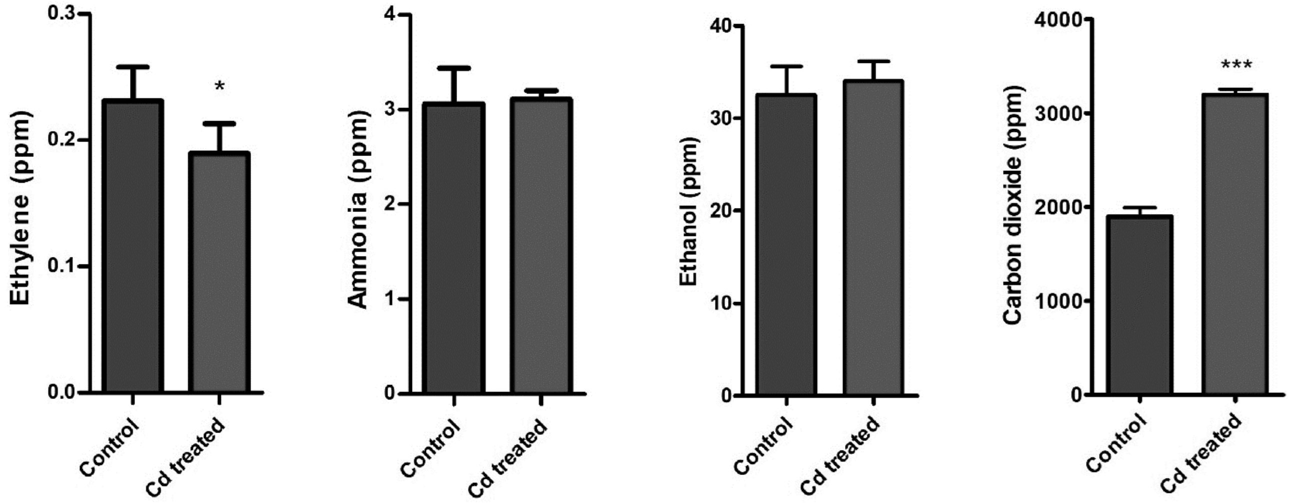

Figure 2. NH_3, C_2H_4, C_2H_5OH and CO_2 production for control or Cd germinated common wheat seeds. *$p < 0.05$, ***$p < 0.001$; Unpaired *t*-test with Welch's correction.

For control plants, the concentrations of the VOCs found in the respiration of the plantlets were about 0.231 ± 0.013 ppm for C_2H_4, 3.063 ± 0.19 ppm for NH_3, 32.50 ± 1.56 ppm for C_2H_5OH and 1898 ± 47.10 ppm for CO_2.

The effect of Cd intake on *Triticum aestivum* seeds growth was detected through changes in the concentrations of the gases emitted.

The ethylene decreased from 0.231 ppm in control samples to about 0.19 ± 0.012 ppm for Cd treated ones. It appears that Cd acts as stress to plantlets and affects the plant physiology.
The NH_3 molecules concentration in the respiration of the plantlets treated with Cd is similar with the one found in control ones, i.e. 3.11 ± 0.045 ppm.

Similar results to control were found for C_2H_5OH molecules, which concentration is about 34 ± 1.08 ppm. However, we found a significant increase in the concentration of CO_2, which reached about 3197 ± 30.43 ppm.

3. CONCLUSIONS

In the present research we analyzed the NH_3, C_2H_4, C_2H_5OH and CO_2 gases molecules using laser photoacoustic spectroscopy at seeds germinated with Cd and we compared the results with the signal respiration of seeds (plantlets) germinated only with distilled water.

Cadmium treatments does not affect NH_3 and C_2H_5OH from in the respiration of plants, while we find a decrease of C_2H_4 and a high increase of CO_2 vapors in the respiration of *Triticum aestivum.*

Using laser photoacoustic spectroscopy, we tried to see if we can find to suggest new and easier methods to assess markers that may contribute to a better understanding of Cd effect. The use of related gases elements in the respiration of plant tissue for seeds treated with Cd is acceptable in theory; metabolic modifications appear in plantlets treated with Cd that inevitably lead to the generation of exceptional metabolites. These elements are transferred through diffusion and the metabolites will then be released into the respiration of plantlets as molecule components of each biological sample.

Based on our findings, we can say that the laser photoacoustic spectroscopy technique could be an easy way to identify biological samples treated with Cd.

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BIBLIOGRAFIE

[1] Popa C., Bratu A.M., Bacalum M., Prepelita P., Application of the laser technology on the effect of Cd phytotoxicity in the detection no of NH3, C2H4, C2H5OH and CO2 biomolecules at Triticum aestivum plantlets, Sustainable Chemistry and Pharmacy, Volume 15, 2020,100208, https://doi.org/10.1016/j.scp.2019.100208.

[2] Guo H. , Hong C. , Chen X. , *et al.*, Different growth and physiological responses to cadmium of the three miscanthus species, PLoS One, 11 (4) (2016), Article e0153475, 10.1371/journal.pone.0153475

[3] Gnana V.S., Beesetti S.I., Mavuluri J., Bharath G., Clarias batrachus: bioindicator to monitor the quality of water in marine communities of South India, Int. J. Ocean. Oceanogr., 12 (2018), pp. 53-65

[4] Emamverdian A., Ding Y., Mokhberdoran F., Xie Y., Heavy metal stress and some mechanisms of plant defense response, Sci. World J. (2015), p. 756120, 10.1155/2015/756120

[5] HangfengW., Jiayue W., Binbin L., Yangjie Ou, W. Junran, S. Qiuyue, J. Wusheng, L. Donghua, Z. Jinhua L. Salix matsudana koidz tolerance mechanisms to cadmium: uptake and accumulation, subcellular distribution, and chemical forms, Pol. J. Environ. Stud., 25 (4) (2016), pp. 1739-1747, 10.15244/pjoes/62715

[6] Bratu Ana Maria, Popa Cristina, Bojan Mihaela, Logofatu Petre Catalin, Petrus Mioara. Non-destructive methods for fruit quality evaluation. Scientific reports, 11(1):7782, 2021.

[7] Dumitras, D.C.; Banita, S.; Bratu, A.M.; Cernat, R.; Dutu, D.C.A.; Matei, C.; Patachia, M.; Petrus, M.; Popa, C. Ultrasensitive CO_2 laser photoacoustic system. Infrared Phys. Tech. J., 53, 308–314, 2010.

[8] Dumitras, D.C.; Bratu, A.M.; Popa, C. CO2, Laser Photoacoustic Spectroscopy: Principles. In CO Laser-Optimisation and Application; Intech Open: London, UK, ISBN 979-953-307-712-2, 2012.

[9] Dumitras, D.C.; Dutu, D.C.; Matei, C.; Magureanu, A.M.; Petrus, M.; Popa, C. Laser photoacoustic spectroscopy: Principles,instrumentation, and characterization. J.Optoelectron. Adv. Mater., 9, 3655–3701, 2007.

[10] Dumitras, D.C.; Bratu, A.M.; Popa, C. CO2 Laser Photoacoustic Spectroscopy: II. Instrumentation and Applications. In CO2 Laser-Optimisation and Application; InTech: Rijeka, Croatia, 2012.

[11] Popa C, Petrus M, Bratu AM, Negut I. Experimental Investigation on Water Adsorption Using Laser Photoacoustic Spectroscopy and Numerical Simulations. Materials (Basel). Oct 6;14(19):5839. doi: 10.3390/ma14195839, 2021.