



SAPP XXV

25th Symposium on Application of
Plasma Processes
and

14th EU-Japan Joint Symposium on
Plasma Processing

Book of Contributed Papers

Štrbské Pleso, Slovakia

31 Jan - 5 Feb, 2025

Edited by G. D. Megersa, E. Maťaš, J. Országh, P. Papp, Š. Matejčík

Book of Contributed Papers: 25th Symposium on Application of Plasma Processes and 14th EU-Japan Joint Symposium on Plasma Processing, Štrbské Pleso, Slovakia, 31 January – 5 February 2025.

Symposium organised by Department of Experimental Physics, Faculty of Mathematics, Physics and Informatics, Comenius University in Bratislava and Society for Plasma Research and Applications in hotel SOREA TRIGAN***.

Editors: G. D. Megersa, E. Maťaš, J. Országh, P. Papp, Š. Matejčík

Publisher: Society for Plasma Research and Applications, Bratislava, Slovakia

Issued: January 2025, Bratislava, first issue

ISBN: 978-80-972179-5-2

URL: <https://neon.dpp.fmph.uniba.sk/sapp/>

Table of Contents

INVITED LECTURES			11
IL-1	Cristina Canal	PLASMA-TREATED HYDROGELS: A THERAPEUTIC ALTERNATIVE IN PLASMA MEDICINE?	12
IL-2	Nicolas Naudé	DIFFUSE DBD AT ATMOSPHERIC PRESSURE: FROM PHYSICS STUDY TO APPLICATIONS	13
IL-3	Jelena Marjanović	BREAKDOWN CHARACTERISTICS IN LOW GWP AND LOW ODP FREONS	16
IL-4	Juraj Fedor	DYNAMICS INDUCED BY ELECTRON COLLISIONS: GASES AND LIQUIDS	21
IL-5	Thierry Belmonte	DISSOCIATING PURE AMMONIA WITH MICROWAVE DISCHARGES	22
IL-6	Oddur Ingolfsson	LOW ENERGY ELECTRONS IN NANO-SCALE PROCESSING	31
IL-7	Inna Orel	SPATIALLY AND TEMPORALLY RESOLVED ELECTRIC FIELD, CURRENT, AND ELECTRON DENSITY IN AN RF ATMOSPHERIC PRESSURE PLASMA JET BY E-FISH	34
IL-8	Dušan Kováčik	ADVANCED DCSBD-BASED PLASMA TECHNOLOGIES FOR SURFACE MODIFICATIONS AND BIO-APPLICATIONS	37
IL-9	Yuzuru Ikehara	PLASMA-BASED MICROFABRICATION TECHNOLOGY FOR CHARGE CONTROL METHODS IN PATHOLOGICAL SPECIMENS: VISUALIZING PHASE TRANSITION LINKED WITH VIRUS PARTICLE FORMATION USING SEM AND AFM	40
IL-10	Toshiaki Makabe	GENERAL RELATIONSHIP BETWEEN DRIFT VELOCITIES IN POSITION AND VELOCITY SPACES OF CHARGED PARTICLES	42
IL-11	Máté Vass	HYBRID FLUID/MC SIMULATIONS OF RADIO-FREQUENCY ATMOSPHERIC PRESSURE PLASMA JETS	53
IL-12	Paula De Navascués	LOW-PRESSURE PLASMA POLYMERIZATION FOR EMERGING FUNCTIONAL MATERIALS	57
IL-13	Jacopo Profili	INVESTIGATING STABLE SURFACE MODIFICATIONS OF FLUOROPOLYMERS BY ATMOSPHERIC PRESSURE NITROGEN DISCHARGE	59
IL-14	Zoltán Juhász	RADIATION CHEMISTRY PROCESSES IN THE SURFACE OF ICY MOONS IN THE PLASMA ENVIRONMENT OF GIANT PLANETS	61
IL-15	Jarosław Puton	SWARMS OF IONS IN VARIABLE ELECTRIC FIELD - POSSIBLE ANALYTICAL APPLICATION	66
IL-16	Masaaki Matsukuma	MULTISCALE SIMULATION OF PLASMA-BASED DEPOSITION PROCESSES	72
HOT TOPICS			73
HT-1	Zdenko Machala	INDOOR AIR CLEANING BY NON-THERMAL PLASMA AND PHOTOCATALYSIS	74
HT-2	Karol Hensel	ELECTRICAL DISCHARGES IN CAPILLARY TUBES AND HONEYCOMB MONOLITHS	77

HT-3	Pavel Veis	TRACE ELEMENTS DETECTION AND CF ELEMENTAL ANALYSIS OF WATER BY LIBS FOR ENVIRONMENTAL CONTROL—COMPARISON OF SURFACE ASSISTED, ACOUSTIC LEVITATION AND NE METHODS	78
HT-4	Zoltán Donkó	THE EFFECT OF NITROGEN ADDITION TO ARGON ON THE Ar 1s ₅ AND 1s ₃ METASTABLE ATOM DENSITIES AND Ar SPECTRAL EMISSION IN A CAPACITIVELY COUPLED PLASMA	79
HT-5	Petra Šrámková	PLASMA TECHNOLOGY AS AN EFFICIENT TOOL TO IMPROVE SEED GERMINATION AND PROVIDE ADHESION OF PROTECTIVE POLYMER COATINGS ON SEEDS	84
HT-6	Satoshi Hamaguchi	MOLECULAR DYNAMICS SIMULATIONS OF SILICON NITRIDE ATOMIC-LAYER DEPOSITION OVER A NARROW TRENCH STRUCTURE	85
HT-7	Jan Benedikt	STABILITY OF METAL-ORGANIC FRAMEWORKS IN NON-THERMAL ATMOSPHERIC PLASMA	86
HT-8	Lenka Zajíčková	PLASMA PROCESSING OF POLYMER NANOFIBERS FOR ENHANCED IMMOBILIZATION OF LIGNIN NANO/MICROPARTICLES	87
HT-9	Ladislav Moravský	ATMOSPHERIC PRESSURE CHEMICAL IONIZATION STUDY OF SULPHUR-CONTAINING COMPOUNDS BY ION MOBILITY SPECTROMETRY AND MASS-SPECTROMETRY	91
HT-10	Jan Žabka	HANKA – CUBESAT SPACE DUST ANALYSER WITH PLASMA ION SOURCE	95
HT-11	Zlata Kelar Tučeková	ATMOSPHERIC PRESSURE PLASMA TREATMENT AND FUNCTIONALIZATION OF GLASS SURFACE FOR RELIABLE ADHESIVE BONDING	97
HT-12	Mário Janda	IN-SITU DIAGNOSTIC OF ELECTROSPRAY BY RAMAN LIGHT SHEET MICROSCOPY	99
HT-13	Matej Klas	MEMORY EFFECT IN PULSED MICRODISCHARGES	105
HT-14	Ihor Korolov	STREAMER PROPAGATION DYNAMICS IN A NANOSECOND PULSED SURFACE DIELECTRIC BARRIER DISCHARGE IN HELIUM-NITROGEN MIXTURES	107
HT-15	Oleksandr Galmiz	GENERATION OF REACTIVE SPECIES VIA SURFACE DIELECTRIC BARRIER DISCHARGE IN DIRECT CONTACT WITH WATER	110

YOUNG SCIENTISTS' LECTURES

114

YS-1	Kristína Trebulová	COLD PLASMA AS AN APPROACH TOWARDS ALTERNATIVE TREATMENT OF OTITIS EXTERNA	115
YS-2	Richard Cimermann	PLASMA-CATALYTIC GAS TREATMENT: THE ROLE OF PELLET-SHAPED MATERIAL IN PACKED-BED DBD REACTORS	118
YS-3	Barbora Stachová	ELECTRON INDUCED FLUORESCENCE OF CARBON MONOXIDE	120
YS-4	Joel Jeevan	EFFECT OF DILUTION OF H ₂ /CH ₄ MICROWAVE MICROPLASMA WITH ARGON FOR IMPROVED GAS PHASE NUCLEATION OF NANODIAMONDS	125
YS-5	Anja Herrmann	MAPPING RADICAL FLUXES WITH THERMOCOUPLE PROBES	131

YS-6	Sandra Ďurčányová	ATMOSPHERIC PRESSURE PLASMA POLYMERIZATION FOR FUNCTIONAL COATING APPLICATIONS	132
YS-7	Ludmila Čechová	PLASMA TREATMENT OF WASTEWATER: A PROMISING APPROACH TO PLANT FERTILIZATION	134
YS-8	Emanuel Maťaš	THERMAL DEGRADATION OF BIODEGRADABLE POLYMERS STUDIED BY IMS TECHNIQUE	136

POSTER PRESENTATIONS

140

P-01	Tom Field	THE TEMPERATURES OF HELIUM AND AIR-FED ATMOSPHERIC PRESSURE PLASMA JETS	141
P-02	Peter Hartmann	IONIZATION-ATTACHMENT INSTABILITY IN AN O ₂ CCRF PLASMA	142
P-03	Amy Jennings	DEVELOPMENT OF AN ANTIBACTERIAL ATMOSPHERIC PRESSURE PLASMA JET	146
P-04	Jana Kšanová	CYCLIC PLASMA-CATALYTIC SYSTEM OF CATALYST DEACTIVATION AND REGENERATION APPLIED FOR VOC REMOVAL	147
P-05	Kinga Kutasi	COMPARISON OF THE MAGNETRON AND THE SOLID-STATE MICROWAVE GENERATOR POWERED SURFACE-WAVE DISCHARGES	149
P-06	Ranna Masheyeva	ON THE IN-SITU DETERMINATION OF THE EFFECTIVE SECONDARY ELECTRON EMISSION COEFFICIENT IN LOW PRESSURE CAPACITIVELY COUPLED RADIO FREQUENCY DISCHARGES BASED ON THE ELECTRICAL ASYMMETRY EFFECT	155
P-07	Mária Maťašová	STATISTICAL CHARACTERIZATION OF VACUUM MICRODISCHARGES GENERATED IN HIGH PULSED ELECTRIC FIELDS	160
P-08	Enmily Garcia	ELECTRON INDUCED DISSOCIATIVE EXCITATION OF FORMAMIDE	163
P-09	Michal Hlína	THERMAL PLASMA GASIFICATION	167
P-10	Mário Janda	ON MECHANISM OF REACTIVE NITROGEN SPECIES FORMATION IN NEGATIVE POLARITY HIGH PRESSURE GLOW DISCHARGE	170
P-11	Gadisa Deme Megersa	LOW ENERGY ELECTRONS INTERACTION WITH ACETONE (CH ₃) ₂ CO IN THE UV-VIS SPECTRAL REGION	179
P-12	Juraj Országh	WATER EMISSION INDUCED BY LOW-ENERGY ELECTRON IMPACT	181
P-13	Samuel Peter Kovár	POTENTIAL ENERGY CURVES OF SPECTROSCOPICALLY RELEVANT EXCITED STATES OF CARBON MONOXIDE: A COMPUTATIONAL STUDY	185
P-14	Vera Mazankova	KINETICS OF OZONE PRODUCTION BY SURFACE PROCESSES	187
P-15	Naomi Northage	EFFECTS OF PLASMA-BASED DISINFECTION METHODS ON THE SURFACE INTEGRITY OF TEFLON	190
P-16	Sandra Ďurčányová	COMPARATIVE STUDY OF PLASMA TREATMENT OF PEA SEEDS WITH DIFFERENT GERMINATION USING TWO PLASMA SOURCES	192

P-17	Mohamed Khalaf Abdelmajeed Fawwaz	EFFECT OF LOW-TEMPERATURE ATMOSPHERIC PRESSURE PLASMA ON GERMINATION, GROWTH PARAMETERS AND DECONTAMINATION OF RADISH SEEDS	196
P-18	Sahila Gahramanli	APPLICATION OF DCSBD AS A LOW-TEMPERATURE PLASMA SOURCE FOR POLYMER PROCESSING	199
P-19	Joel Jeevan	FUTURE TO FACILE SEEDING TECHNOLOGY: FROM NANODIAMOND TO NANOCRYSTALLINE DIAMOND FILM	202
P-20	Bernard Gitura Kimani	INVESTIGATING THE COMBINED ANTIYEAST EFFICACY OF PLASMA-ACTIVATED WATER AND NATURAL PHENOLICS ON PLANKTONIC DEBARYOMYCES HANSENII	205
P-21	Lenka Krejsová	STUDY OF DIRECT AND INDIRECT PLASMA APPLICATION ON ONION SEEDING BULBS	209
P-22	Adriana Mišúthová	EFFECT OF PLASMA-ACTIVATED WATER ON PHYSIOLOGICAL PARAMETERS IN BEAN PLANTS (PHASEOLUS VULGARIS)	215
P-23	Joanna Pawlat	INFLUENCE OF APPJ ON PRIMARY TEETH ENAMEL	220
P-24	Petra Šrámková	APPLICATION OF NON-THERMAL PLASMA GENERATED BY PIEZOELECTRIC DIRECT DISCHARGE ON SEEDS AND STUDY OF ITS EFFECT	222
P-25	Tomáš Vozár	INFLUENCE OF PLASMA ACTIVATED WATER ON THE PLANT GROWTH AND VITALITY	225
P-26	Dawid Zarzeczny	QUALITY STUDY OF FRESH PRESSED CARROT JUICE AFTER COLD ATMOSPHERIC PLASMA TREATMENT	229
P-27	Jozef Brcka	MULTISCALE TIME EVOLUTION OF C ₂ H ₂ +Ar MIXTURE DECOMPOSITION IN LOW-PRESSURE INDUCTIVELY COUPLED PLASMA	231
P-28	Oddur Ingolfsson	DISSOCIATIVE IONISATION OF PENTAFLUOROPHENYL TRIFLATE, A POTENTIAL PHOTO ACID GENERATOR FOR CHEMICALLY AMPLIFIED EXTREME ULTRAVIOLET LITHOGRAPHY RESISTS	233
P-29	Oddur Ingolfsson	DISSOCIATIVE ELECTRON ATTACHMENT TO PENTAFLUOROPHENYL TRIFLATE, A POTENTIAL PHOTO ACID GENERATOR FOR CHEMICALLY AMPLIFIED EXTREME ULTRAVIOLET LITHOGRAPHY RESISTS	235
P-30	Peter Čermák	ACCURATE REFERENCE DATA FOR MONITORING OF AMMONIA	237
P-31	Martin Kuřka	MEASUREMENT OF ION CURRENT FROM MULTI-HOLLOW SURFACE DIELECTRIC BARRIER DISCHARGE	239
P-32	Filip Pastierovič	DUAL-CHANNEL ABSORPTION SPECTROSCOPY	244
P-33	Peter Tóth	EMISSION SPECTRA OF TRANSIENT SPARK WITH ELECTROSPRAY	246
P-34	Neda Babučić	MASS SPECTROMETRY OF DIELECTRIC BARRIER DISCHARGE WITH WATER ELECTRODE	251
P-35	Vahideh Ilbeigi	RAPID DETECTION OF VOLATILE ORGANIC COMPOUNDS EMITTED FROM PLANTS BY MULTICAPILLARY COLUMN-ION MOBILITY SPECTROMETRY	257
P-36	Priyanka Kumari	STUDY OF PLASMA-ASSISTED REACTION OF PENTANE AND AMMONIA BY ATMOSPHERIC PRESSURE CHEMICAL IONIZATION ION MOBILITY-MASS SPECTROMETRY (IMS-MS)	261

EFFECT OF PLASMA-ACTIVATED WATER ON PHYSIOLOGICAL PARAMETERS IN BEAN PLANTS (*PHASEOLUS VULGARIS*)

Adriana Mišúthová¹, Zuzana Lukačová², Mustafa Ghulam³, Ramin Mehrabifard¹,
Božena Šerá³, Zdenko Machala¹

¹ Division of Environmental Physics, Comenius University Bratislava, Slovakia

² Department of Plant Physiology, Comenius University Bratislava, Slovakia

³ Department of Environmental Ecology and Landscape Management, Comenius University
Bratislava, Slovakia

E-mail: adriana.misuthova@fmph.uniba.sk

Our study explores the effects of plasma-activated water (PAW) used for seed priming, foliar application, and their combination on key physiological parameters of bean plants *Phaseolus vulgaris* (hybrid Petronilla) cultivated over three months under field conditions. The findings reveal that PAW treatments significantly enhanced the leaf area, the chlorophyll concentration, and the activity of selected antioxidant enzymes, demonstrating its potential to improve plant growth and stress resilience. These results highlight the effectiveness of PAW as a sustainable agricultural intervention to optimize crop performance in field conditions.

1. Introduction

The growing global population highlights the urgent need for sustainable food production. Modern agriculture heavily relies on commercial fertilizers, with nitrogen being a critical nutrient for plant growth [1, 2]. However, emerging physical methods like static magnetic fields, pulsed electric fields, and cold atmospheric gas plasmas offer innovative and potentially sustainable solutions, though their effects on plants require further investigation [3, 4]. One promising development a source of nitrogen is plasma-activated water (PAW), generated by electrical discharges in contact with water. Its chemical composition, including reactive oxygen and nitrogen species (RONS) like hydrogen peroxide (H_2O_2), nitrites (NO_2^-), and nitrates (NO_3^-), varies based on the plasma discharge type, interaction method, and water buffering capacity [5]. Hydrogen peroxide enters plant cells via facilitated diffusion through aquaporins, playing a crucial role in plant cells and tissues signalling, while NO_2^- and NO_3^- act as essential nitrogen sources, transported through specific transporters [6–9]. These properties position PAW as a sustainable, eco-friendly alternative to traditional fertilizers. This study explores the effects of different PAW applications, such as seed priming and foliar treatments, on bean plants. We examined its impact on key morphological and physiological parameters, including leaf area, concentration of chlorophylls, soluble phenolics, and selected antioxidant enzymes activity in young leaves of adult plants.

2. Methodology

Bean plants were cultivated over a three-month period in 90-liter pots located in the open-air atrium of the Faculty of Natural Sciences at Comenius University Bratislava. Each pot contained nine plants, and the study included the following experimental treatments: the control, seeds primed with PAW, the foliar application of PAW, and the combination of seed priming and foliar application. For priming, seeds were immersed in PAW for 8 hours. Bean seeds were soaked in plasma-activated water under controlled conditions, then air-dried before sowing. After drying seeds were sown directly into the pots. This treatment aimed to enhance germination and early plant growth. Foliar treatments were applied weekly, with each seedling receiving 3 mL of PAW per application. PAW was sprayed on Bean plants, starting when plants had three true leaves and continuing until flowering. Applications were done in early morning using a hand pump pressurized bottle to ensure even coverage.

PAW was prepared by batch treatment of regular tap water (pH=7.9) with multiple parallel transient spark (TS) discharges [10], typically 170 ml of tap water was treated by 17 discharges during 10 min.

Schematic diagram of TS plasma is shown in Fig 1. Each TS was set at approximately 1 kHz repetition frequency of the pulses and 1 cm distance of the power high voltage electrodes from the water surface. The PAW was applied to the plants fresh, within 10 min from the treatment. In such conditions its chemical characteristics were typically as follows: pH=7.5, concentrations of $\text{H}_2\text{O}_2 = 452 \mu\text{M}$, $\text{O}_3 = 10 \mu\text{M}$, $\text{NO}_2^- = 980 \mu\text{M}$, $\text{NO}_3^- = 1.7 \text{ mM}$.

After three months, young leaves were sampled to evaluate the effects of plasma-activated water (PAW) on various physiological parameters. Leaf area was measured using the Image J software. Chlorophyll concentration was determined following the protocol described by Lichtenthaler [11]. Soluble phenolic content was quantified using the method outlined by Ainsworth and Gillespie [12]. In addition, the activity of the key antioxidant enzymes, including superoxide dismutase (SOD) [13], ascorbate peroxidase (APX) [14], guaiacol peroxidase (G-POX) [15] and catalase (CAT) [16] was monitored. Statistical analysis was conducted using Statgraphics Centurion XV version 15.2.05 (StatPoint, Inc., Warrenton, VA, USA) and Microsoft Excel (Microsoft Office). Treatment effects were assessed via analysis of variance (ANOVA), with single-step multiple comparisons performed, and the least significant difference (LSD) test applied at a significance level of $P < 0.05$.

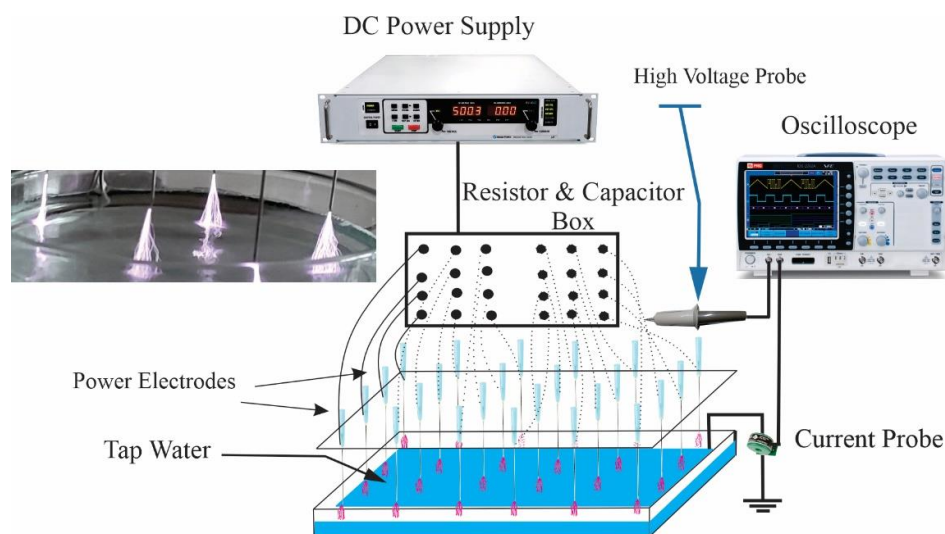


Fig. 1. Schematic diagram of transient spark discharge.

3. Results and Discussion

The foliar application of PAW significantly enhanced the leaf area of young bean plants, with a notable increase compared to the control. The combination of seed priming and foliar application resulted in the most pronounced differences, producing the largest leaves. A positive effect of PAW was also observed in chlorophyll concentration, a key indicator of photosynthetic activity, with a significant increase observed across all treatments compared to the control (Fig. 2). However, in the priming & spraying treatment, chlorophyll *a* concentration was significantly lowered compared with other PAW treatments. PAW acts as a nitrogen source for plants. Nitrate, essential for photosynthesis, supports chlorophyll synthesis in leaves contributing to their growth and development. This highlights the potential of PAW to enhance both physiological and biochemical parameters critical for plant productivity.

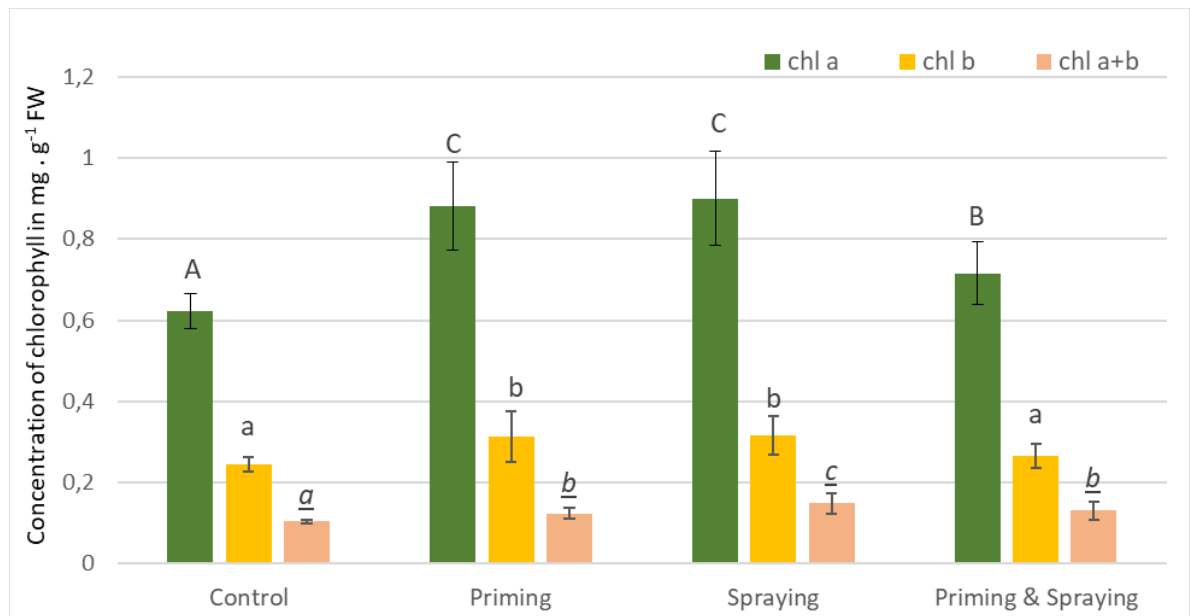


Fig. 2. Chlorophyll concentration in $\text{mg} \cdot \text{g}^{-1}$ fresh weight (FW) in young bean leaves. Different letters represent statistically significant differences among the treatments at $P \leq 0.05$.

Antioxidant enzymes are essential components of a plant's defence mechanism against environmental stresses. Superoxide dismutase is an essential enzyme in plant defence mechanisms against oxidative stress. Superoxide dismutase catalyses the dismutation of superoxide radicals into H_2O_2 , which must subsequently be reduced to water to prevent oxidative damage. This critical step is facilitated by other enzymes in the antioxidant system, such as APX, G-POX and CAT, which exhibit high substrate affinity for H_2O_2 . All three applications of PAW resulted in increased SOD activity compared to the control (Fig. 3A). While H_2O_2 plays a signalling role in stress responses, its excessive concentrations result in oxidative damage, compromising cellular integrity. Peroxidases are critical enzymes in detoxifying ROS, catalysing the conversion of H_2O_2 into water through electron donation, thereby protecting cells from oxidative stress [17]. A notable increase in APX activity was observed in seeds primed with PAW, and in the treatments combining seed priming with foliar application (Fig. 3B). Conversely, the foliar application alone did not significantly affect APX activity. In this case, the G-POX enzyme demonstrated the highest activity, suggesting a compensatory mechanism to manage ROS levels under this treatment condition (Fig. 3C). The differing reactions of these two peroxidases can be attributed to their distinct roles and locations: G-POX is a secretory extracellular enzyme, whereas APX is intracellular. Consequently, they operate in different environments and participate in distinct pathophysiological processes. Similarly, CAT activity was elevated in every PAW treatment relative to the control (Fig. 3D), likely due to its role in scavenging the oxidative effects of H_2O_2 present in PAW. Chen et al. [18] previously demonstrated that appropriate nitrogen application enhances the concentrations of SOD and CAT in sweet potato, findings consistent with the results of this study. The elevated levels of these antioxidant enzymes in this experiment suggest an improved tolerance to oxidative stress induced by ROS. During the vegetative stage, plants experience an increased demand for nitrogen to support their rapid growth. The application of PAW during this critical phase may effectively meet this nitrogen requirement, as PAW contains high concentrations of nitrite (NO_2^-) and nitrate (NO_3^-). This nitrogen supply likely contributes to the observed increase in chlorophyll content (Fig. 2) and the enhanced activity of antioxidant enzymes (Fig. 3), which can be attributed to the reactive nitrogen species (RNS) delivered through PAW treatments.

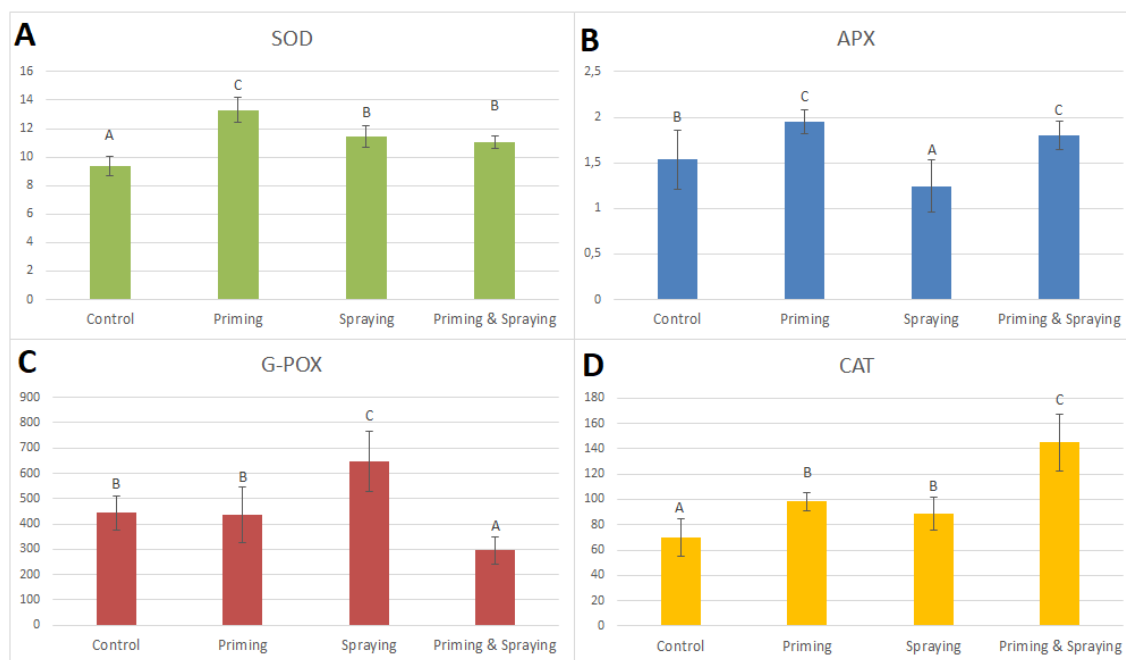


Fig. 3. Activity of SOD (A), APX (B), G-POX (C) and CAT (D) antioxidant enzymes in young leaves of beans plants. Different letters represent statistically significant differences among the treatments at $P \leq 0.05$.

4. Conclusion

Our study demonstrates that PAW significantly enhances adult bean plant growth and oxidative stress tolerance. Plasma activated-water treatments increased the leaf area and chlorophyll content in young bean plants, with the combination of seed priming and foliar application yielding the most significant effects. Furthermore, different application of PAW elevated the activity of almost all monitored key antioxidant enzymes, enhancing the plants' ability to mitigate oxidative damage. By providing reactive nitrogen species (RNS) and nitrates, PAW effectively meets nitrogen demands during critical vegetative growth stages, thereby improving physiological performance and stress resilience.

5. Acknowledgements

The research was supported by the EU project NextGenerationEU through the Recovery and Resilience Plan for Slovakia under the projects No. 09I03-03-V02-00036, Environmental applications of electrical discharges for water, air cleaning, and agriculture No. 09I03-03-V03-00033(EnvAdwice) and by the Grant Slovak Research and Development Agency No. APVV-22-0247.

6. References

- [1] Masclaux-Daubresse C, Daniel-Vedele F, Dechorgnat J, Chardon F, Gaufichon L and Suzuki A 2010 *Annals of Botany* **105**, 1141–1157.
- [2] Sharma A 2017 *International Journal for Research in Applied Science and Engineering Technology* **5**, 677–680.
- [3] Reina F.G, Pascual L.A and Fundora I.A 2001 *Bioelectromagnetics* **22**, 596–602.
- [4] Sonoda T, Takamura N, Wang D, Namihira T and Akiyama H 2014 *IEEE Transactions on Plasma Science* **42**, 3202–3208.
- [5] Zhou R, Zhou R, Wang P, Xian Y, Mai-Prochnow A, Lu X, Cullen P.J, Ostrikov K and Bazaka K 2020 *Journal of Physics D: Applied Physics* **53**, 303001.
- [6] Kučerová K, Henselová M, Slováková L, Bačovčinová M and Hensel K 2021 *Applied Sciences* **11**, 1985.