



ANNUAL MC & SCIENTIFIC MEETING

PRIMSEEDPOWER

plant priming in the context of mitigating climate change

SARAJEVO 2026

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ANNUAL MC & SCIENTIFIC MEETING

Plant Priming and Stress Memory for Climate Change Mitigation

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BOOK OF ABSTRACTS

Plant Priming and Stress Memory for Climate Change Mitigation

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PLENARY LECTURES

CRITICAL ROLE OF EDUCATION ON SOIL HEALTH IN THE CONTEXT OF CLIMATE CHANGES

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Abstract

In the time of constant yet unpredictable and growing effects of climate change, all segments of the global ecosystem are under constant pressure and threat. The major attention has been traditionally given to warming, quality, and pollution of air, endangered water resources, biodiversity depletion... However, what often stays behind the public scrutiny and without a wider debate is the status and vulnerability of the most visible element of our environment – the omnipresent and inevitable soil. Addressing this issue and being part of the EU's Mission Soil, the Horizon Europe project LOESS – *Literacy boost through an Operational Educational Ecosystem of Societal actors on Soil health*, aims to analyse and provide an overview of the current level of soil-related knowledge across Europe. LOESS maps, connects and engages with multiple actors through the Communities of Practice (CoPs) in 15 European countries, to explore educational needs amongst school pupils, students, and young professionals. The project made a diverse range of innovative teaching programmes and resources, with the instrumental role being given to the creation of an original and completely new Atlas of Soil Education. All these resources target different stages of education, connecting them with global and local challenges of climate change, biodiversity loss, and the UN's Sustainable Development Goals (SDGs). The Center for the Promotion of Science coordinates a work package tasked with capacity building and campaigning. To ensure efficient and effective dissemination, use, and exploitation of tools, knowledge, and experiences, different media channels, networking activities, and methods are deployed through four tailored campaigns for the extended use of produced modules and materials. These campaigns target key actors and stakeholders – policymakers, researchers, university professors and students, school principals, teachers and pupils, and the general audience. Through this holistic approach, the goals and messages of the project and the Mission Soil are adequately communicated and put into action.

Keywords: Soil, soil health, soil education, climate transition, Mission Soil

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FROM RECALL TO RESET: THE ROLE OF DNA (DE)METHYLATION IN PLANT IMMUNE MEMORY

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Abstract

Plants recovering from pest or pathogen attack often retain a heightened state of defence, known as induced resistance (IR). This state is typically driven by a priming of the innate immune system, enabling faster and stronger responses upon subsequent stress exposure. Our lab investigates the epigenetic foundations of this immune memory in plants. Our previous work has shown that early exposure of Arabidopsis seedlings to biotic stress triggers long-lasting immune priming that persists throughout the life cycle and, in some cases, is partially inherited to the next generation. This immune memory is associated with reductions in DNA methylation and requires the activity of the DNA demethylase REPRESSOR OF SILENCING 1 (ROS1). To dissect how DNA demethylation contributes to immune memory, we are employing genetic approaches to manipulate the plant's DNA methylome. Using epigenetic recombinant inbred lines (epiRILs), which share the same genetic (wild-type) background but vary in heritable DNA methylation, we have previously identified specific epialleles that prime defence gene expression and provide high levels of disease resistance without growth penalties. Building on these findings, we have developed a new method to introduce dosed amounts of ROS1-dependent DNA de-methylation into plant genomes. This approach not only enables the engineering of epigenetic disease resistance in crops but also provides a powerful tool to investigate how plants establish, maintain, and reset stress-specific immune memory.

Keywords: Plant immune priming, epigenetic stress adaptation, DNA (de)methylation.

Acknowledgement: The authors would like to acknowledge the support of the UKRI-BBSC and European Research Commission under grant numbers BB/W015250/1 and 101199639 (PlantMemo), respectively. Participation in the PrimSeedPower Conference "Plant Priming and Stress Memory for Climate Change Mitigation" was supported by COST Action CA24156 – Seed Priming Solutions: Boosting Crop Resilience for a Sustainable Future.

MACHINE LEARNING-DRIVEN RGB PHENOTYPING FOR *Arabidopsis thaliana* GROWTH AND STRESS MAPPING

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Abstract

High-throughput RGB imaging offers a non-invasive method for screening plant growth and stress responses across different growth stages. In *Arabidopsis thaliana*, automated image analysis is essential because visual datasets rapidly become too large for manual assessment and require reproducible transformation into measurable traits. This study focuses on an RGB-based phenotyping pipeline designed to quantify rosette morphology and detect colour-defined stress patterns within background-suppressed plant canopies. After separating the rosette from the soil, the pipeline extracts a broad set of shape descriptors from rosette masks, including projected rosette area, perimeter, width, convex hull, bounding box, circle and ellipse measurements, roundness, compactness, eccentricity, surface coverage, and temporal growth rates. Additional contour-derived measurements capture local deviations from circularity, allowing a detailed description of rosette outline structure and leaf arrangement at the canopy boundary. Alongside geometric analysis, the pipeline incorporates colour-based assessment of physiological status. Healthy tissue is identified in HSV colour space using clustering-derived colour intervals. Regions outside the healthy mask are then classified as stressed canopy area, enabling calculation of both healthy and stress-affected rosette regions. Dominant colour clusters are extracted separately from healthy and stressed regions, and RGB colour-distance traits are calculated relative to green, yellow, and purple reference colours. These colour traits support discrimination between green photosynthetically healthy tissue, purple anthocyanin-associated stressed tissue, and yellow senescent tissue. Together, the proposed pipeline provides an interpretable framework for linking rosette architecture, canopy growth, stress area, and tissue colour changes in large-scale indoor phenotyping experiments.

Keywords: plant phenotyping, *Arabidopsis thaliana*, RGB imaging, computer vision, trait analysis

EPISEEDLINK. FROM SEED TO SEEDLING: EPIGENETIC MECHANISMS OF PRIMING TO DESIGN STRATEGIES FOR CROP IMPROVEMENT

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Abstract

The overarching mission of EpiSeedLink is to foster a European Network that empowers crop improvement through epigenetics by providing expertise, know-how, and creativity in high-end technologies to 11 early-stage scientists and enabling them to translate scientific knowledge and skills into innovation. Through international, multidisciplinary, and inter-sectorial training in experimental and computational biology, EpiSeedLink aims to contribute to excellence in research but also to timely address societal and agricultural needs. This original research program combines the unique know-how of academic experts with that of two companies to synergize research and knowledge transfer between a plant model (*Arabidopsis*) and a crop of enormous agro-economic importance (oilseed rape).

EpiSeedLink explores epigenetic regulation of seed priming mechanisms to improve crop performance under threats caused by climate change (drought, heat, high light) through non-GMO practices.

Keywords: Seed priming, seed vigour, stress tolerance, PhD training, know-how transference, oilseed rape

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MITOCHONDRIAL CONTROL OF PLANT DEVELOPMENT, GROWTH, AND STRESS RESILIENCE

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Abstract

Mitochondria are essential for development, growth, and stress responses through energy metabolism, organelle biogenesis, and stress-responsive signalling across developmental contexts. Although essential for aerobic ATP production in all eukaryotes, plant mitochondria are necessary for efficient photosynthetic metabolism by providing ATP, redox balancing, and metabolic flexibility required for chloroplast function. Mitochondrial biogenesis is highly dynamic, transitioning from pro-mitochondria in seeds to fully competent organelles during germination and expanding through growth and division cycles that support meristematic proliferation. Disruption of protein import, genome maintenance, or respiratory chain assembly consistently results in developmental defects, including retarded growth, altered organ patterning, and compromised meristem integrity. Mitochondrial genomes also shape developmental outcomes through chimeric ORFs that drive cytoplasmic male sterility, illustrating how organelle–nuclear interactions influence reproductive success. Proteomic profiling reveals organ specificity that is responsive to environmental conditions. As environmental sensors, mitochondria orchestrate plant responses to abiotic and biotic stress. Perturbations in respiration, redox balance, or metabolite flux activate retrograde signalling pathways integrating mitochondrial and chloroplast signals, with hormonal networks, to adjust transcriptional and post-transcriptional regulation of cellular function. In this presentation, I will outline our research on mitochondrial biogenesis and stress signalling and how this regulates plant performance. I will present a cellular view of how plants respond to perturbation of mitochondrial function and the role of mitochondria in seed development and germination. These latest findings open up new avenues for smart breeding using synthetic biology approaches to prime the new generation of plant breeding for sustainable agriculture.

Keywords: Mitochondria, Retrograde signalling, Biogenesis, Stress Tolerance, Cellular resolution



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ORAL PRESENTATIONS

PRIMING MODES AND INVESTIGATION OF EPIGENETIC MEMORY AT WHEAT - CASE STUDIES IN ALBANIA

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Abstract

Here, we present a collection of approaches followed to evaluate the response and epigenetic memory of local cultivars in use in Albania (*T. aestivum* L.) to abiotic and biotic stresses: repeated HT, salinity, HB treatment, and infection by *Fusarium*, during early development. Tolerance to two subsequent HT treatments at 30°C/2hrs were investigated based on plants' metabolomics (GC-MC/HPLC-MS), morphometric parameters, fine root cells death, RWC, pigments, total carbohydrates, and Rubisco activase (Rca2 β , Rca1 β , Rca2 α) expression. Both *Fusarium*-infected (inf) and non-infected (non-inf) plants were used to evaluate their possible role in the memory to HT. Also, FCS naturally present were identified based on Tef1 α gene sequences (Fusaroid-ID; NCBI). Mycotoxins were extracted from seeds (QuEChERS), and characterised (LC-MS/MS) to understand their role in plants' response to HT. Tolerance to HB was investigated using different HBs (tribenuron-methyl, 2,4 D, and their combination), and by verifying the impact of the mode of application (pre-treatment of seeds or spraying on plants). Also, a study on the short-term effect of tribenuron-methyl concentrations (0.5 M, 1 M, 1.5 M) in wheat cultivars and two wheat ancestors (*Aegilops*) was conducted. The impact of salinity (NaCl 0-50-100-200mM) in growth parameters, pigment content, GSH content, and expression of rubisco genes (rbcL/S) during seedling was also evaluated. In conclusion, we have a preliminary classification of the tolerant vs non-tolerant cvs, which will be further studied to elucidate the molecular mechanisms behind their resistance.

Keywords: HT-high temperature, HB-herbicide, biotic/abiotic stress, epigenetic memory, FCSs-*Fusarium* Complex Species

Acknowledgement: The authors would like to acknowledge the support of this work by the project "Use of molecular tools for the early detection of *Fusarium* infection & Evaluation of tolerance towards abiotic stresses of wheat (*Triticum aestivum* L.) local cultivars in use in Albania", which was implemented under the National Program for Research & Development of Albania 2023-2024, funded by the Albanian National Agency for Scientific Research & Innovation (NASRI). Participation in the PrimSeedPower Conference "Plant Priming and Stress Memory for Climate Change Mitigation" was supported by COST Action CA24156 – Seed Priming Solutions: Boosting Crop Resilience for a Sustainable Future.

BEYOND CONVENTIONAL PRIMING: MOLECULAR REWIRING AND NANOMATERIAL INTERFACES IN PLANT STRESS ADAPTATION

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Abstract

Global agricultural production is suffering substantial losses due to climate change-related weather events such as drought and salinity, leading to tissue damage and, ultimately, major yield losses. The development of sustainable, 'green' technologies is therefore of utmost importance, also due to the need for reduced agrochemical use. Nanotechnology provides invaluable tools to a variety of industrial sectors. Increasing attention is being given to the development and optimization of nanomaterials for application in the agricultural industry towards protection against stress and improved growth, based on their small size, high surface-to-volume ratio, and unique optical properties. The current presentation gives an up-to-date description of the main research activities carried out at the Cyprus University of Technology with the employment of advanced nanomaterials and polymers applied at the plant and seed level. This technology offers an attractive alternative to established approaches such as conventional breeding and genetic modification, with key advantages, representing a characteristic example of integrative plant physiology where multiple disciplines, such as materials science, agriculture, and analytical chemistry, join forces to develop exciting new tools in modern agriculture.

Keywords: Nanomaterials, plant priming, abiotic stress, nanoparticles, polymer coatings

Acknowledgement: Participation in the PrimSeedPower Conference "Plant Priming and Stress Memory for Climate Change Mitigation" was supported by COST Action CA24156 – Seed Priming Solutions: Boosting Crop Resilience for a Sustainable Future.

MICROBIAL PRIMING RESPONSES IN SPRING BARLEY: IMPACTS ON GROWTH AND DISEASE RESISTANCE

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Abstract

Microbial priming can enhance crop resilience and partially compensate for the negative effect of combined stress conditions in the field. Barley production is reduced by foliar diseases such as leaf rust (LR), net blotch (NB), powdery mildew (PM), and spot blotch (SB). A diverse set of 182 spring barley genotypes was investigated for susceptibility to four different fungal diseases (LR, NB, PM, SB) in response to two priming inducers, *Ensifer meliloti* (Em) and *Serendipita indica* (Si). The highest percentages of barley genotypes with significant ($p < 0.05$) primability were observed for Em as priming inducer and NB (61%) and LR (42%) as priming challengers. Genome-wide association studies (GWAS) were performed for barley priming efficiency (PE) of each priming inducer/ priming challenger system. GWAS revealed specific marker-trait-associations (MTAs) for PE of Em/LR (30), Em/NB (35), Si/PM (13), and Em/SB (9). Two hotspots with shared quantitative trait locus (QTL) regions for priming efficiency were observed: first of Em/NB and Em/SB on chromosome 1H, and second, Em/LR and Si/PM on chromosome 3H, and are covering candidate genes important for the general response of barley to microbial priming. Genotypes that positively responded to bacterial priming for resistance to both diseases ($p < 0.001$) were selected for further experiments. Root and shoot growth of plants were promoted by C14 AHL in a hydroponic system. Combined-pathogen response test (*P. hordei* and *P. teres f. teres*) indicates that the priming efficiency may differ from the results obtained in a single-pathogen system. For field trials, seeds were coated with *E. meliloti*, *B. pumilus*, and *B. velezensis* (ABiTEP GmbH) before sowing. Reductions of naturally occurring leaf rust and powdery mildew symptoms, as well as changes in yield-related parameters, were genotype and strain-dependent. Markers selected from GWAS results were converted to KASP markers that can be used to select for primable genotypes in pre-breeding.

Keywords: Microorganisms, QTL, AHL, *Bacillus*, barley

Acknowledgement: The authors would like to acknowledge the support of Federal Ministry of Research, Technology and Space for the project “Priming for enhanced defense as a strategy to optimize crop resistance and as a possible breeding target - PrimedPlant3” under grant number FKZ: 031B0196. Participation in the PrimSeedPower Conference “Plant Priming and Stress Memory for Climate Change Mitigation” was supported by COST Action CA24156 – Seed Priming Solutions: Boosting Crop Resilience for a Sustainable Future.

THE FUTURE IS NOW: AI, ACADEMIC ETHICS AND SCIENCE COMMUNICATION FOR EARLY-CAREER RESEARCHERS

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Abstract

Artificial intelligence is increasingly shaping the research environment in which early-career researchers develop their academic skills, communicate findings, and participate in scientific communities. In areas such as plant priming and climate change-related research, artificial intelligence tools can support literature review, data analysis, visualization, academic writing, and science communication, while also raising ethical questions related to transparency, authorship, originality, fairness, and responsible presentation of scientific results. This workshop aims to provide early-career researchers with a dedicated space to explore these opportunities and risks, exchange practical experiences, and strengthen professional connections. The session will begin with a brief introduction to key ethical and practical challenges linked to the use of artificial intelligence in research and science communication. Participants will then engage in interactive small-group discussions using a World Café format, focusing on how artificial intelligence is changing research practices, how its use can remain responsible and transparent, and what skills and values researchers need to apply these tools ethically. The workshop is expected to support peer learning, networking, and critical reflection, while encouraging responsible research practices in a rapidly changing scientific landscape. By focusing on early-career researchers, the session will contribute to aligning innovation with research integrity, trust, and high-quality science communication.

Keywords: Artificial intelligence; early-career researchers; research integrity; science communication; responsible research practices.

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ASCORBIC ACID SEED PRIMING AND DEHYDRIN RESPONSE UNDER SALT STRESS IN MAIZE

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Abstract

One of the major abiotic stresses limiting agricultural productivity globally is salinity. Seed priming is a successful approach to improve stress tolerance, particularly during the early stages of plant growth. This study investigates the effects of ascorbic acid (AsA) based seed priming on the physiological and molecular responses of salt-stressed maize. Under controlled conditions, maize seeds were primed with AsA and exposed to different concentrations of NaCl. Physiological parameters such as ion leakage, turgor loss, and total chlorophyll content were evaluated, along with biochemical and protein-level analyses. The results showed that AsA priming improved plant water status, reduced ion leakage, and helped maintain chlorophyll content under salinity stress. In addition, primed plants exhibited higher proline accumulation and increased total protein content, indicating improved stress adaptation. SDS-PAGE and immunoblot analyses confirmed that dehydrin proteins were strongly induced under salt stress and further enhanced by priming treatments. These findings demonstrate that AsA-based seed priming enhances salt stress tolerance in maize through coordinated physiological and molecular mechanisms. Overall, this study highlights the potential of seed priming as a valuable tool for sustainable agriculture and provides insights into the role of stress-related proteins in priming-induced stress responses.

Keywords: Ascorbic acid, protein profiling, salinity, seed priming, *Zea mays* L.

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ROLE OF AUXIN AND CYTOKININ INTERACTIONS DURING TOMATO GAMETOGENESIS AND EMBRYOGENESIS UNDER HIGH-TEMPERATURE STRESS AND IN INTERSPECIFIC HYBRID SEED VIGOR

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Abstract

Hormones are crucial in many physiological processes in plants. This research aimed to clarify the roles of auxin and cytokinin (CK) and their interactions during pollen and seed development. We used transcriptomics, hormonal profiling, and proteomics (multi-omics) to study how hormones regulate flower organ development in tomatoes. To better understand how auxin and CK interact, we tracked auxin response factors (DR5) and the CK response factor (TCS) during flower and fruit development. The primary metabolome, proteome, hormonal levels, and response dynamics changed significantly in tomato hybrid seeds [*Solanum Lycopersicum* x *Solanum Habrochaites*]. These hormonal changes correlated with low germination rates in these hybrids, which may limit their use in breeding programs aimed at improving abiotic stress tolerance in tomatoes. Previous findings and our current research suggest that auxins and CK control tomato gametogenesis and embryogenesis. Interestingly, we identified new expression patterns of CK response around the pollen sac (tapetum), the embryo sac (nucellus), and pollen cells. We propose that auxin and CK are essential for male and female gametogenesis. Our studies also show that auxin and CK interact and do not always act antagonistically; their interactions vary across flower and fruit cells and organs during development. Both hormone responses decreased in flower organs under temperature stress, and these decreases were linked to pollen viability and flower development. We highlight the novel role of hormonal regulation in gametogenesis, embryogenesis, late seed development, and reproductive barriers. Further studies are needed to uncover the molecular mechanisms behind these hormonally regulated processes.

Keywords: Embryo, endosperm, germination, hormones

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DECODING ELECTRO-PRIMING-INDUCED GERMINATION AND BIOCHEMICAL RESPONSES IN COTTON THROUGH INTEGRATED TAGUCHI DESIGN-MACHINE LEARNING MODELING

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Abstract

Cotton (*Gossypium hirsutum* L.) is one of the most economically significant fiber crops worldwide. Inconsistent germination, delayed emergence, and weak early vigor limit cotton production under fluctuating environmental conditions. These limitations are often associated with restricted water uptake, oxidative stress during imbibition, and suboptimal activation of metabolic and antioxidant pathways. Seed priming techniques have been widely adopted to mitigate early-stage constraints by initiating controlled physiological and biochemical processes before radicle protrusion. In this study, cotton seeds were primed with electric intensity (EI) at different exposure times (ET). Data was analyzed with classical analysis of variance (ANOVA). To optimize the electro-priming treatments, an integrated approach of using Taguchi Design (TD) with machine learning models was employed for germination metrics, morphological traits, and biochemical markers. TD model identified EI as the most dominant factor, with the highest signal-to-noise (S/N) ratio observed for DPPH and dry weight. Analyzing the results of ML algorithms revealed the better performance of ensemble-based models like random forest and ExtraTrees compared to boosting-based and kernel-based models. However, it was observed that the predictive reliability of the model was dependent on the trait, and no single algorithm was found optimal. Results were further optimized by the feature-importance analysis, which validated the findings of TD and identified EI as the most dominant predictor for all traits. The integrated ANOVA-TD-ML approach indicates EI as a primary driver of EP and demand fine-scale optimization to maximize biochemical enhancement without altering germination physiology.

Keywords: Participation in the PrimSeedPower Conference “Plant Priming and Stress Memory for Climate Change Mitigation” was supported by COST Action CA24156 – Seed Priming Solutions: Boosting Crop Resilience for a Sustainable Future.

SELECTED QUESTIONS TO CONSIDER BEFORE APPLYING SEED NANOPRIMING

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Abstract

Seed nanopriming is increasingly considered a promising tool for improving seed performance, plant establishment, and seed health. At the same time, its practical use requires careful evaluation of several factors that substantially influence the final outcome. This contribution summarizes selected aspects that should be considered before the technology is applied on a broader scale. Particular attention is paid to the characterization of the applied nanomaterials, since their composition, morphology, stability, and reproducibility directly affect both biological activity and the interpretation of results. Based on our own experimental data, the importance of optimizing concentration and treatment duration will be demonstrated, as these parameters strongly determine whether the effect is stimulatory, neutral, or undesirable. The presentation will also highlight the necessity of including an appropriate wet control, because part of the observed response may result from hydropriming itself rather than from the nanoparticles alone. In addition to effects on germination and early seedling growth, attention will be given to present examples of phytosanitary effect of nanopriming, including its potential contribution to the suppression of seed-borne pathogens and to improved plant health in subsequent stages of cultivation. From a practical perspective, it is equally important to consider how long the positive effect of treatment persists and at what point after application the seeds should be sown to achieve the intended benefit. Overall, the contribution aims to demonstrate, using our own data, how selected factors can influence the nature of the results and to present nanopriming as a promising technology whose success depends on making appropriate methodological choices.

Keywords: seed nanopriming, nanoparticles characterisation, hydropriming, phytopathogen control

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MULTISPECTRAL 3D PHENOTYPING FOR SEED PRIMING EFFECTS ON LEGUME GROWTH DYNAMICS

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Abstract

Multispectral 3D phenotyping has emerged as an advanced, non-destructive approach for precise monitoring of plant growth, morphology, and physiological status. In this study, high-resolution multispectral 3D imaging was used to analyze growth dynamics and evaluate the effects of biostimulant seed priming on biomass accumulation in six legume genotypes. The experiment included two alfalfa cultivars (Birutė and Milda), two crimson clover cultivars (Kardinal and Redhead), and two zigzag clover genotypes (Melot and breeding line 260z). Five morphological traits—digital biomass, 3D leaf area, average plant height, canopy light penetration depth, and convex hull area—were quantified alongside three spectral indices: Green Leaf Index (GLI), Normalized Difference Vegetation Index (NDVI), and Normalized Pigment Chlorophyll Index (NPCI). Phenotyping was performed biweekly, resulting in nine scans for alfalfa and crimson clover and six for zigzag clover. Final validation included manual measurements of plant height and shoot fresh and dry weights. Results showed that alfalfa and crimson clover accumulated biomass and height more rapidly than zigzag clover. However, zigzag clover, particularly genotype 260z, exhibited the strongest positive response to treatment, including increased biomass and higher NDVI values, indicating improved physiological performance. Positive effects were also observed in Melot, Redhead, and Birutė. Analysis of variance revealed strong species effects ($p < 0.001$), weak treatment effects, and no significant species $\times$ treatment interactions. A reduction in NPCI ($p = 0.0047$) suggests potential stress mitigation. Strong correlations between digital, dry, and fresh biomass ($r = 0.68, 0.73, 0.93$; $p < 0.001$) and plant height ($r = 0.95$, $p < 0.001$) confirm the reliability of multispectral 3D phenotyping. These findings highlight genotype-specific responses and support its application as a robust phenotyping tool.

Keywords: High-throughput phenotyping, biostimulant, plant 3D model, vegetation index

Acknowledgement: Participation in the PrimSeedPower Conference “Plant Priming and Stress Memory for Climate Change Mitigation” was supported by COST Action CA24156 – Seed Priming Solutions: Boosting Crop Resilience for a Sustainable Future.



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plant priming in the context of mitigating climate change

SARAJEVO 2026

FLASH TALKS

STRESS MEMORY EFFECT ON MULTIPLE STRESS TOLERANCE IN PLANTS

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Abstract

Plants are sessile organisms confined to a single habitat, which means they must constantly deal with multiple stressors throughout their lives. Their limited seed dispersal further increases the likelihood that offspring will encounter similar stressors across generations. Given the ongoing effects of climate change and various anthropogenic pressures, plants are increasingly exposed to multiple stressors, which makes understanding how plants develop multiple stress tolerance of growing importance. While different stresses might be perceived by specialized sensory systems, because of common signaling pathways the signal tends to converge, leading to a common stress response. The aim of this study is to determine whether prior exposure of parental *Arabidopsis thaliana* plants to chromium (Cr) could contribute to tolerance of their offspring to different types of stressors. Seeds from Cr-primed parents and unprimed wild-type plants were germinated under controlled conditions and then transferred to hydroponic systems, where they were exposed to three types of stresses: salt (NaCl), osmotic (polyethylene glycol, PEG), and heavy metal (cadmium, Cd) stress. To evaluate the effects on plant growth, shoot and root length, fresh and dry mass, and photosynthetic pigment content were measured. Biochemical responses were assessed by determining osmolyte content (proline and soluble sugars) and antioxidative enzyme activity. This study could contribute to a better understanding of the molecular basis and physiological mechanisms behind priming-induced multiple stress tolerance and potentially open up new, ecologically acceptable strategies for improving crop resilience.

Keywords: Stress priming, transgenerational memory, cross-stress tolerance, crop resilience

Acknowledgement: Participation in the PrimSeedPower Conference “Plant Priming and Stress Memory for Climate Change Mitigation” was supported by COST Action CA24156 – Seed Priming Solutions: Boosting Crop Resilience for a Sustainable Future.

A SEED AGEING AND PRIMING RESPONSES IN *Triticum aestivum*: ESTABLISHING A CONTROLLED EXPERIMENTAL FRAMEWORK FOR PHYSIOLOGICAL AND EPIGENETIC ANALYSES

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Abstract

Seed ageing is a major constraint to crop establishment, reducing germination, seed vigor, and uniformity under variable environmental conditions. Seed priming has emerged as a cost-effective and sustainable strategy to enhance germination performance, although its underlying mechanisms remain only partially understood. This ongoing study aims to establish an experimental framework to investigate seed ageing and priming responses in wheat (*Triticum aestivum*). A controlled accelerated ageing procedure is being optimized to generate reproducible levels of seed deterioration under defined temperature and humidity conditions. Different ageing durations (24-96h) at 42 °C, were evaluated to identify a consistent deterioration window corresponding to partial germination loss, suitable for downstream priming assays. Preliminary results indicate that ageing conditions strongly influence germination outcomes. A moderate ageing condition (48 h) was identified as suitable for testing priming treatments, including hydropriming, chemical priming (ascorbic acid), and nanoprimering (metal oxide nanoparticles) approaches. Their effects on germination performance are currently under evaluation. Physiological and biochemical measurements will be integrated with future epigenetic analysis, including DNA methylation, as a potential mechanism underlying priming-induced response. This work focuses on developing a robust and scalable experimental system to study seed ageing and priming interactions, providing a foundation for future epigenetic analysis of seed performance.

Keywords: *Triticum aestivum*; Seed ageing; Seed priming; Germination; DNA methylation.

Acknowledgement: The authors would like to acknowledge the support of Rita Abranches, Plant Cell Biology, ITQB NOVA, for support of this work, Catarina F. Santos, IST, for the help in the nanoparticles synthesis, Fundação para a Ciência e Tecnologia (FCT) (contract 2023.08161. CEECIND), the Research Unit “GREEN-IT Bioresources for Sustainability” R&D Unit (UID/04551/2025, DOI: 10.54499/UID/04551/2025), and the Entrepreneurship and Innovation Award of Crédito Agrícola/Long Living Seeds. Participation in the PrimSeedPower Conference “Plant Priming and Stress Memory for Climate Change Mitigation” was supported by COST Action CA24156 – Seed Priming Solutions: Boosting Crop Resilience for a Sustainable Future.

SHADING AND DEFICIT IRRIGATION INDUCE PHOTOCHEMICAL ACCLIMATION IN GREENHOUSE SWEET PEPPER

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Abstract

Crop responses to water deficit are strongly modulated by the light environment, particularly under greenhouse conditions where shading nets can be established. However, the combined effects of shading and deficit irrigation on photosystem II (PSII) performance and yield formation are not fully understood. This study investigated the interactive effects of shading and deficit irrigation on the photochemical performance and productivity of greenhouse-grown sweet pepper (*Capsicum annuum* L.) „Florina“. Plants were cultivated during spring-summer period in northern Greece, where shading nets are typically installed from May onwards. From that time, two shading levels (30% and 60%) and three irrigation regimes (100%, 75%, and 50% of crop evapotranspiration, ET_c) were applied. At mid-growth stage (70 days after transplantation - DAT), moderate water deficit under lower shading (30%–75% ET_c) resulted in the highest PSII performance (OJIP parameters; Plabs and Pl_{tot}), indicating a stimulatory effect of mild stress. This pattern persisted at the end of the crop cycle (104 DAT), where all treatments under 30% shading maintained higher PSII performance compared to those under 60% shading. In contrast, increased shading (60%) significantly reduced photochemical performance across irrigation levels, particularly under water deficit. Maximum quantum efficiency (F_v/F_m) remained stable across treatments. Agronomic results showed that shading enhanced vegetative growth, while deficit irrigation maintained and even enhanced yield levels. Overall, the results in pepper indicate that, unlike in some crops, increased shading during the warmer months limits photosynthetic performance due to reduced light availability.

Keywords:

Chlorophyll fluorescence, photosystem II, climate resilience, shading nets, *Capsicum annuum*

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HOW Brassicaceae AND Leguminosae SEEDS RESHAPE THEIR SPECIALIZED METABOLOME FOR STRESS RESPONSE AND ADAPTATION

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Abstract

Specialized metabolites (SMs) strongly influence seed quality by modulating stress tolerance and developmental traits. In seeds of *Brassicaceae* and *Leguminosae* species, a diverse array of SMs is present, with compositions highly responsive to environmental conditions and playing key ecological roles, notably in protection against desiccation, heat, and pathogens. Our team has been investigating the effects of environmental stresses and nutrient availability on seed SM composition, as well as how seeds reshape their specialized metabolome in response and adaptation to these stresses. Using multi-omics approaches and functional analyses, we have shown that seeds of *Brassicaceae* species (*Arabidopsis thaliana*, *Camelina sativa*, and *Brassica napus*) and *Leguminosae* species (*Pisum sativum* and *Phaseolus vulgaris*) are able to adjust their specialized metabolome in response to stress and/or different environments. The results highlight strong environmental plasticity of the SM profile, along with a marked genotype effect on metabolite diversity in certain species, particularly common bean. We also explored the ecological roles of key metabolites, notably glucosinolates (*Brassicaceae*) and isoflavonoid-derived compounds (*Leguminosae*), in defense responses against seed pathogens. Overall, our work reveals a conserved metabolic response to stress alongside genotype-specific regulatory patterns, providing new insights into the mechanisms underlying seed quality and stress resilience.

Keywords: Seeds, specialized metabolites, abiotic stress, biotic stress, environmental plasticity

Acknowledgement: Participation in the PrimSeedPower Conference “Plant Priming and Stress Memory for Climate Change Mitigation” was supported by COST Action CA24156 – Seed Priming Solutions: Boosting Crop Resilience for a Sustainable Future.

CEVALUATION OF PHYTOEXTRACTS FROM AROMATIC PLANTS AS HYDRO-PRIMING AGENTS FOR THE ORGANIC CULTIVATION OF TOMATO

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Abstract

The application of phytoextracts with high biological activity is an eco-sustainable alternative to the use of agrochemicals, especially when their antimicrobial effect is associated with the bio-stimulation of the natural defenses of the plant itself, right from the seed stage. Many species are already known to be particularly rich in secondary metabolites that are toxic to pathogenic organisms and/or useful for facing environmental stresses. The project 'ESOPO' aims at selecting and evaluating commercial, hydro-alcoholic extracts from aromatic plants for their possible use as biopesticides and biostimulants in the organic cultivation of tomato. An in vitro screening was performed to exclude the phytotoxic effect on seed germination and development when extracts were applied as seed coating at different concentrations. Those extracts that did not show any adverse effects in terms of germination, root elongation, and seed vigor were investigated further: developmental, physiological, biochemical, and molecular traits have been evaluated on plantlets grown from treated and non-treated seeds, showing a differential effect amongst extracts. Based on obtained results, blackcurrant and juniper phytoextracts were selected to be tested as hydropriming agents for *S. lycopersicum* cv Sailor, to investigate their biological potential for enhance plant fitness also during the induction of salt stress: plants from primed seeds were grown in controlled conditions and repeatedly treated with 100 mM NaCl, then biomass production, antioxidant profile, proline and chlorophylls content and other physiological features were evaluated. Currently, field trials are ongoing to establish the performance of hydroprimed seeds in real conditions.

Keywords: Phytoextract; Seed priming; Organic tomato cultivation; Salt stress

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BIOSTIMULANTS AND THEIR EFFECT ON THE PATHOGEN SUSCEPTIBILITY AND DROUGHT STRESS RESILIENCE OF OATS

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Abstract

Climate change is leading to an increase in extreme weather events, such as drought stress, and to conditions that promote the occurrence of certain plant pathogens, such as oat crown rust. Both can result in significant crop failures. Consequently, research is increasingly focusing on biostimulants as alternatives to chemically synthesized pesticides to reduce susceptibility to pathogens or increase tolerance to drought stress. This study aims to test if the priming inducers *Ensifer meliloti* or *Bacillus* successfully applied in barley and wheat are transferable to oats and to test the effect of priming on oat-specific pathogens and drought stress. For this purpose, a set of 39 oat accessions was tested for their priming efficiency with regard to crown rust, loose smut, and drought stress. Various biostimulants were used as priming inducers. The partially commercial products were used in a range of applications, including seed coating. Preliminary results from greenhouse experiments show a significantly ($p < 0.05$) decreased crown rust infestation after treatment with *Bacillus* or a commercial biostimulant product. Furthermore, significant genotype-specific priming effects were detected after treatment with the priming inducers *Ensifer meliloti* or *Trichoderma*. The results should help to improve the integrated plant protection of oats through an innovative combination of priming inducers and oat genetics, to reduce the use of environmentally harmful plant protection chemicals, and at the same time sustainably promote the competitiveness of oat cultivation.

Keywords: Oat, crown rust, drought stress

Acknowledgement: The authors thank the Federal Ministry of Agriculture, Food and Regional Identity for funding the project (FKZ: 28220E186). Participation in the PrimSeedPower Conference “Plant Priming and Stress Memory for Climate Change Mitigation” was supported by COST Action CA24156 – Seed Priming Solutions: Boosting Crop Resilience for a Sustainable Future.

COMPARATIVE GENETIC ANALYSIS OF *Triticum aestivum* VARIETIES UNDER SALT STRESS: INTEGRATING MORPHOLOGICAL AND BIOCHEMICAL TRAITS

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Abstract

Wheat (*Triticum aestivum* L.), a staple crop crucial for global food security, faces significant productivity challenges due to salinity stress in many agricultural regions. This study investigates the response of ten wheat varieties to salinity stress, focusing on seven agronomic and ten biochemical traits. All agronomic traits showed a significant reduction under salinity stress. Varieties V1 (NARC), V3 (SEHER), and V7 (DILKASH 2020) exhibited better performance under salinity stress in terms of agronomic and biochemical traits compared to other varieties. The biochemical traits revealed increased levels of proline, glycine betaine, lipid peroxidation, and Na⁺ content under stress, while other traits decreased. The genetic components of these traits identified membrane integrity index, K⁺ content, relative water content, and plant height as promising indicators of salinity stress tolerance. Further, we revealed complex trait interactions through correlation analysis and identified direct and indirect effects through path coefficient analysis, providing insights into the wheat varieties' responses to salinity stress. Overall, this research offers valuable insights into wheat performance and adaptability under salinity stress, supporting future breeding for resilience.

Keywords: Wheat, Salinity, Ion toxicity, Genetic analysis

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POLYAMINES AS PRIMING AGENTS TO ALLEVIATE COPPER AND GLYPHOSATE COMBINED TOXICITY IN TOMATO PLANTS

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Abstract

As climate change intensifies soil degradation and agrochemical dependency, the co-occurrence of pesticides such as copper (Cu) and glyphosate (GLY) in agricultural soils is becoming increasingly frequent, threatening crop productivity and food security. Both contaminants impair plant growth and cause severe physiological and redox disorders, particularly under combined exposure. Therefore, strategies to mitigate their hazards in crop growth and development are needed. Polyamines, namely Spermidine (Spd), are promising candidates, given their roles in plant cell signalling and stress protection. However, their potential as priming agents against pesticide-induced phytotoxicity, especially under co-exposure scenarios, remains poorly understood. This study investigated whether priming tomato (*Solanum lycopersicum* L.) seedlings with Spd could enhance their resilience upon subsequent exposure to combined Cu and GLY stress. To do so, tomato seedlings were foliar-sprayed with Spd (100 μ M) for two weeks before transfer to agricultural soils contaminated or not with a mixture of Cu (75 mg kg⁻¹) and GLY (10 mg kg⁻¹). After 28 days, co-exposure to Cu and GLY significantly reduced organ elongation and plants' fresh biomass, with a more pronounced impact on roots, decreased chlorophyll and carotenoid content, and disrupted redox homeostasis. Spd priming partially restored photosynthetic integrity and upregulated non-enzymatic antioxidant defenses, namely proline and glutathione. However, its effectiveness may have been limited by the foliar application, considering that soil contaminants predominantly affect roots. Altogether, these findings establish Spd-based priming as a promising tool for enhancing tomato resilience under pesticide-mixture stress, highlighting the need to optimize application strategies to maximize its protective potential.

Keywords: Environmental contamination; herbicides; metals; non-target plants; oxidative stress; spermidine; stress tolerance

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DROUGHT-MEDIATED PRIMING INDUCES STRESS MEMORY IN *Castanea sativa* MILL. THROUGH COORDINATED PROTEOMIC, REDOX, AND HORMONAL REPROGRAMMING

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Abstract

Over recent years, pre-exposure to mild drought has emerged as a promising priming strategy to enhance plant stress tolerance; however, its underlying mechanisms in woody species remain poorly understood. Here, we investigated how drought stress memory modulates the physiological, redox, hormonal, and proteomic responses of *Castanea sativa* to subsequent drought stress. Young chestnut plants were first exposed to mild drought [35% maximum water holding capacity (WHC_{max}); 21 days], followed by rewatering (70% WHC_{max}; 7 days), and later subjected to severe drought (25% WHC_{max}). After 30 days of stress, unprimed plants showed clear signs of oxidative damage, accompanied by strong activation of abscisic acid (ABA) signalling and accumulation of stress-related proteins. In contrast, drought-primed plants did not exhibit such responses and maintained redox homeostasis, indicating lower susceptibility to drought. These plants also displayed a distinct proteomic profile associated with greater metabolic stability. Notably, evidence of stress memory was observed even in primed plants under non-stressed conditions, which showed activation of protective pathways and repression of energetically costly processes. Moreover, many differentially abundant proteins were shared between primed-control and primed-stressed plants, supporting efficient proteomic reprogramming induced by prior drought exposure. Hormonal profiling further reinforced this memory-based response: priming prevented ABA overaccumulation under drought while promoting a jasmonic acid-enriched hormonal state independently of stress exposure. Overall, our results demonstrate that drought priming induces stress memory in *C. sativa* through coordinated adjustments in proteomic, redox, and hormonal regulation, enabling a more efficient and energetically cost-effective response to severe drought.

Keywords: abiotic stress tolerance; chestnut plant; climate change; water deficit; plant physiology; proteome.

IMPROVING GERMINATION AND ANTIOXIDANT PROPERTIES OF MICROGREENS THROUGH SEED PRIMING

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Abstract

Physical seed priming and natural plant extracts were evaluated for their effects on germination, early growth, and bioactive quality of selected *Brassicaceae* microgreens, including red cabbage, radish, and broccoli. Germination and early seedling establishment represent critical stages that determine plant vigor and nutritional potential. Three treatments were applied: an untreated control, hydropriming, and pre-sowing exposure to chamomile extract. Germination percentage, germination rate, seedling vigor, and biomass yield were assessed to evaluate early growth performance. In addition, total phenolic and flavonoid contents, as well as antioxidant capacity, were analyzed to determine the bioactive quality of the microgreens. The study investigates whether simple priming techniques can enhance seed performance through mild stress conditioning and stimulate the accumulation of bioactive compounds. This approach aims to provide low-cost and sustainable strategies for improving early plant development and functional properties of *Brassicaceae* microgreens.

Keywords: *Brassicaceae*, hydropriming, chamomile extract, bioactive quality.

Acknowledgement: Participation in the PrimSeedPower Conference “Plant Priming and Stress Memory for Climate Change Mitigation” was supported by COST Action CA24156 – Seed Priming Solutions: Boosting Crop Resilience for a Sustainable Future.

A CULTUROMIC PROTOCOL FOR THE DETERMINATION OF FUNCTIONALLY ACTIVE SEED MICROBIOTA

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Abstract

Seed-associated microbiota play a critical role in early plant development, yet their functional characterization remains limited by methodological constraints in microbial isolation. Here, we present a reproducible protocol designed to determine functionally active seed microbiota through the integration of optimized surface sterilization and controlled germination prior to microbial isolation. The method establishes a systematic framework to identify minimal sterilization conditions, using ethanol and sodium hypochlorite combinations, that effectively remove epiphytic contaminants while preserving endogenous microbial populations. This step is coupled with axenic seed germination, allowing microbial communities to respond to host developmental cues under sterile conditions. In contrast to conventional approaches based on direct maceration of dry seeds, this strategy promotes the activation and enrichment of microbial taxa that are initially rare or dormant. Application of the protocol to tomato (*Solanum lycopersicum*) seeds demonstrates a consistent increase in the recovery of specific culturable bacterial taxa during germination, including genera such as *Stenotrophomonas*, *Paenibacillus*, and *Priestia*. Notably, microbial groups representing a minor fraction in dry seeds (~3-5%) are enriched during early seedling development (up to ~15-20%), suggesting functional relevance in plant establishment. This protocol provides a robust and adaptable approach for the culturomic exploration of seed microbiota, enabling the isolation of microorganisms actively interacting with emerging seedlings. It offers a valuable tool for advancing studies on seed microbiome assembly, plant-microbe interactions, and the identification of microbial candidates for sustainable agriculture.

Keywords: Seed microbiome, culturomics, seed germination, microbial isolation, biological seed priming

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plant priming in the context of mitigating climate change

SARAJEVO 2026

POSTER PRESENTATIONS

PRE-SOWING TREATMENTS OF *Quercus robur* L. ACORNS AND THEIR EFFECTS ON GERMINATION AND EARLY SEEDLING GROWTH

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Abstract

In Croatia, pedunculate oak forests are recognised as the backbone of the forestry due to the many ecosystem services they provide. This importance is reflected in the fact that 64,7 % of seedlings produced in 2025 in Croatian forest nurseries are pedunculate oak. However, as cultivation methods vary among forest tree species, the type, duration, and intensity of applied practices must be carefully considered. Different cultivation methods can result in seedlings of varying quality and adaptability to field conditions. This study aims to evaluate the effects of pre-sowing acorn treatments on acorn viability, moisture status, susceptibility to pathogens, seed coat permeability, germination dynamics, and early seedling development. Analysis shows that the most commonly applied treatments include thermotherapy, scarification, and seeding density adjustment. Thermotherapy helps maintain acorn viability and protects against certain fungal infections. Scarification promotes more uniform germination and may positively affect root system development, while lower seeding density significantly influences the development of seedling morphological attributes. However, there is still a lack of systematic studies that monitor seedling growth and development over multiple growing seasons. It remains unclear whether the initial advantages gained through these treatments persist or diminish over time under varying site conditions. Despite these limitations, certain cultivation practices can have an important role in improving seedling quality, which can ultimately enhance survival, initial growth, and development, particularly under challenging climate conditions.

Keywords: Forest reproductive material, nursery production, morphological attributes, pedunculate oak

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SEED PRIMING UNDER COMMON SOIL DEGRADATION CONSTRAINTS: A FIELD VALIDATION SYSTEM

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Abstract

Seed priming is recognized and increasingly promoted as a low-cost practice to improve crop development and stress tolerance, but its performance in farmers' fields is often variable because seeds emerge under varying soil conditions and limitations. In Croatian agroecosystems, the most widespread forms of degradation include soil compaction, soil erosion by water, excessive acidity, soil salinity, and seasonal water shortage. This work proposes a field validation procedure that explicitly utilizes soil limitations in priming trials to support protocol standardization and uptake. Annual croplands are first stratified using a minimal diagnostic set consisting of several indicators like bulk density or penetration resistance, infiltration and surface sealing indicators, aggregate stability, pH, electrical conductivity, and soil water availability. Secondly, a small set of practical priming options (e.g., hydropriming, nutrient priming, or biopriming) is then compared with non-primed seed, applying standardized establishment metrics (time to 50% emergence, final emergence, within-plot uniformity, early biomass, and rooting depth). Looking at priming effects alongside soil limitations reveals whether priming is enough, or whether we first need to mitigate the soil degradation by adopting several soil management practices like traffic control and residue cover for compaction and erosion, liming for acidity, gypsum or improved drainage for saline patches, and water conserving practices under drought risk. This scheme aims to improve cross-site comparability and accelerate farmer-relevant uptake of seed priming under climate variability.

Keywords: Seed priming; soil compaction; soil erosion; acidity; field validation

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SEED PRIMING INDUCED ENHANCEMENT OF HEAVY METAL TOLERANCE IN *Silene sendtneri*

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Abstract

Seed priming represents a promising strategy for enhancing plant tolerance to abiotic stress by activating physiological, biochemical, and molecular defense mechanisms prior to stress exposure. In this study, the endemic Balkan species *Silene sendtneri* was investigated to evaluate the effects of different seed priming treatments on tolerance and accumulation capacity under cadmium (Cd) and lead (Pb) stress. Seeds were subjected to hydropriming and chemical priming using salicylic acid (SA), proline (PP), and silicic acid (SiA), followed by exposure to varying concentrations of Cd and Pb under controlled in vitro conditions. The effects of priming were assessed through an integrative analysis including germination performance, biomass production, photosynthetic pigments, proline accumulation, mineral composition, metal uptake and translocation, phenolic acids, flavonoid profiles, and transcriptomic responses. Results demonstrated that priming significantly improved germination and plant growth under heavy metal stress, although responses varied depending on the priming agent and metal type. Proline- and salicylic acid-based priming treatments showed particularly strong effects in maintaining biomass, enhancing antioxidant-related metabolites, and modulating metal accumulation patterns. Cadmium stress induced broader systemic metabolic and transcriptional responses, whereas Pb stress predominantly activated structural and cell wall-associated defense mechanisms. Transcriptomic analysis revealed differential regulation of genes associated with metal transport, antioxidative defense, phenylpropanoid metabolism, and stress signaling pathways, indicating that priming induced a coordinated molecular reprogramming that enhanced stress preparedness. Integration of physiological and transcriptomic datasets suggests that distinct priming agents activate different adaptive strategies, ranging from stabilization of cellular homeostasis to enhanced signaling and compensatory metabolic flexibility. Overall, this study demonstrates that seed priming can significantly improve heavy metal tolerance in *Silene sendtneri* while modulating its phytoremediation potential. The findings provide new insights into the mechanistic basis of priming-induced stress resilience and highlight the potential application of priming approaches for improving the performance of metal-tolerant plants in contaminated environments.

Keywords:

Seed priming, *Silene sendtneri*, heavy metal stress, cadmium, lead, salicylic acid, proline, silicic acid, phytoremediation, transcriptomics, abiotic stress tolerance

Acknowledgement:

Participation in the PrimSeedPower was supported by COST Action CA24156 – Seed Priming Solutions: Boosting Crop Resilience for a Sustainable Future.

UPCYCLING ORGANIC LEMON PEEL WASTE: SEED PRIMING BENEFITS VS. AQUATIC TOXICITY RISKS IN *Artemia salina*

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Abstract

This study investigated the bioactive potential of lemon peel (LP) extract, rich in flavonoids and phenolic acids, by evaluating its effects on the germination of *Lactuca sativa* L. and its cytotoxicity using the *Artemia salina*-Brine Shrimp Lethality Test (BSLT). The primary objective of this research was to evaluate the bioactive potential of lemon peel extract as a natural priming agent for enhancing the germination and early development of *Lactuca sativa* L., while simultaneously assessing its aquatic toxicity using *A. salina*. An aqueous 5% (w/v) LP stock solution was used for both assays. Lettuce seeds were primed for 2 hours in solutions before being cultured on hormone-free MS medium for 7 days. Simultaneously, *A. salina* larvae were exposed to 0.25% and 0.5% concentrations, with mortality and morphology assessed after 48 hours via Nikon Eclipse microscop observation. In lettuce, the 0.5% treatment yielded the highest germination (40%) and superior growth parameters, whereas the 5% concentration significantly inhibited development. In the BSLT, the 0.5% group exhibited 80% mortality after 48 hours, showing tissue necrosis, intestinal granulation, and inhibited growth compared to the control (846.93 μm). The results demonstrate a dose-dependent response consistent with hormesis, where moderate concentrations (0.5%) act as biostimulants for seedling vigor, while higher concentrations induce phytotoxicity and significant aquatic mortality. While lemon peel extract can enhance early plant development, its application must be carefully managed to avoid inhibitory effects and possible environmental toxicity.

Keywords: Lemon peel, *Lactuca sativa* seed priming, brine shrimp, morphology

BIOACTIVITY PROFILING OF *Artemisia annua* L.: CORRELATING BRINE SHRIMP LETHALITY WITH INHIBITORY EFFECTS ON SEED DEVELOPMENT IN *Amaranthus retroflexus* L.

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Abstract

The current study explores the bioherbicidal potential of *Artemisia annua* L., a plant traditionally known for its medicinal properties, by examining its effects on the highly invasive weed *Amaranthus retroflexus* L. (pigweed) and the brine shrimp *Artemia salina*. Using aqueous extracts at concentrations of 2.25 mg/mL and 4.5 mg/mL, the research aimed to evaluate both allelopathic suppression of plant growth and potential cytotoxicity. The results revealed a dual nature of the extract. In the brine shrimp assay, the extract had stimulating effects on growth (reaching 1020.74 μm at the lower dose compared to 832.15 μm in the control), yet showed toxicity at higher concentrations, confirmed by a 30% mortality rate and irregular swimming patterns. This suggests that it may promote growth due to its antioxidant capacity, but the extract becomes hazardous as the dosage increases. Regarding its impact on pigweed, the findings were more definitive. There was a clear, concentration-dependent inhibition across all tested categories. Germination rates dropped from 53.3% to 33.3% at a concentration of 4.5 mg/mL. Both root and shoot lengths were inhibited, and fresh biomass showed a significant reduction from 0.036 g to 0.024 g. These outcomes highlight that *A. annua* contains potent allelochemicals capable of disrupting the early life cycle of a major agricultural weed. The extract significantly inhibited the growth of *A. retroflexus*, while preliminary tests on *Artemia salina* indicate minimal impact on aquatic fauna, highlighting its potential as an environmentally safe bioherbicide.

Keywords: Ragweed, brine shrimp nauplii, wormwood

LONG-TERM VIABILITY OF ENCAPSULATED *Pseudomonas* sp. AND MOLECULAR INSIGHTS INTO ROOT-POLYMER INTERACTIONS FOR ENHANCED RHIZOSPHERE COLONIZATION

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Abstract

The long-term viability of plant growth-promoting (PGP) bacteria is a key determinant of successful microbial inoculant performance in sustainable agriculture. Encapsulation within biopolymer matrices offers a promising strategy to protect beneficial bacteria from abiotic stress and enable their gradual release into the rhizosphere. However, optimizing encapsulation systems requires consideration of both bacterial survival and the physicochemical compatibility of the polymer matrix with plant root surfaces. This study investigated the long-term viability of *Pseudomonas* sp., isolated from serpentine soil in Central Bosnia, encapsulated in 2% (w/v) sodium alginate beads (750 µm diameter) produced using a Büchi encapsulator and stored at +4 °C for one year. Viability was assessed via colony-forming unit (CFU) counts following surface sterilization and homogenization of capsules. In parallel, molecular docking analyses were performed to evaluate the interaction potential between four biopolymers — sodium alginate, guar, chitosan, and pectin — and five root-expressed proteins (CEVI-1, NHX3, NHX4, OPR2, and XEGIP) identified from bioprimered seedlings whose parental generation had been exposed to acute nickel stress. These proteins are associated with stress response, ion transport, and cell wall modification. After one year of storage, encapsulated *Pseudomonas* sp. maintained a viable cell count of 7.1×10^6 CFU g⁻¹, confirming the protective capacity of the sodium alginate matrix. Docking analyses revealed that guar exhibited the strongest binding affinities (−7.2 to −8.6 kcal mol⁻¹), followed by chitosan (−7.1 to −8.0 kcal mol⁻¹) and sodium alginate (−6.4 to −6.8 kcal mol⁻¹), while pectin showed the weakest interactions. These results suggest that while sodium alginate ensures reliable long-term bacterial survival, guar and chitosan demonstrate superior molecular compatibility with root-associated proteins. Future work will focus on molecular dynamics simulations and the functional validation of chitosan-based PGP bacterial capsules across diverse crops.

Keywords: Bacterial encapsulation, Sodium alginate, Molecular docking, Root-polymer interactions, Sustainable agriculture

GERMINATION PERFORMANCE OF *Abies alba* SEEDS FROM MISTLETOE-INFECTED AND NON-INFECTED TREES

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Abstract

This study assessed seed germination of *Abies alba* from mistletoe-infected and non-infected trees in natural populations in Bosnia and Herzegovina. Seed germination and quality are key indicators of early plant establishment and are linked to stress tolerance and regeneration under changing environmental conditions. Cones were collected from four natural populations, with 10 trees per population. Mistletoe presence or absence was recorded for each tree. Seeds from the central parts of cones were germinated in Petri dishes under standard laboratory conditions on 12 March 2021, with 100 seeds per tree. Germinated seeds were counted on 26 March 2021 and at 5–7 day intervals until 23 April 2021. At the final assessment, non-germinated seeds were dissected and classified as healthy, empty, or decayed. Descriptive statistics and ANOVA were performed using SPSS 20.0, with population and mistletoe infection as factors. ANOVA showed no significant differences in total germination or in the proportions of healthy, empty, and decayed non-germinated seeds in relation to mistletoe infection. However, significant differences ($p < 0.05$) among populations were found in early germination and in healthy and decayed non-germinated seeds at final assessment. Kladanj showed the highest early germination, while Drvar showed none initially. Kaljina Bioštica had the highest number of healthy non-germinated seeds. These results indicate that mistletoe infection does not significantly affect seed germination or quality in *A. alba*, while population-level variation suggests a stronger influence of local ecological and genetic factors on seed performance under early establishment conditions.

Keywords: Silver fir, biotic stress (mistletoe infection), seed germination, seed quality, forest regeneration

TRANS-GENERATIONAL MAINTENANCE OF ENDOPHYTE-INDUCED DNA METHYLATION IN A HOST REPORTER GENE

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Abstract

Beneficial endophytic fungi establish associations with plants that enhance host growth, stress tolerance, and resistance to pathogens. Beyond these physiological effects, increasing evidence suggests that plant-microbe interactions may also influence host gene regulation through epigenetic mechanisms, such as DNA methylation. Because DNA methylation can be mitotically and, in some cases, meiotically inherited, microbe-induced epigenetic changes could contribute to long-term plant adaptation and stress memory. However, the extent to which beneficial endophytes can induce heritable DNA methylation changes in their hosts remains largely unexplored. We aimed to investigate the possibility of transgenerational inheritance of DNA methylation induced by a beneficial fungal endophyte to its host. To address this, we used an experimental system consisting of the GFP-overexpressing *Nicotiana benthamiana* 16C line (Nb-GFP16C) and a transgenic *Fusarium solani* strain K (FsK) that harbors a hairpin GF construct that is partially complementary to the plant's GFP sequence (FsK-hpGF) (Dalakouras et al., 2023; Kellari et al., 2025). This artificial system serves as an RNAi sensor and has previously been used to show that FsK-hpGF colonizes only the root system of *N.benthamiana*, yet is able to trigger post-transcriptional gene silencing and dense DNA methylation of the host GFP sequence in both roots and leaves of Nb-GFP16C plants. Progeny derived from colonized plants were analyzed with bisulfite sequencing in the absence of the endophyte to evaluate the inheritance of epigenetic marks. Our study provides preliminary evidence that beneficial fungal colonization can induce epigenetic changes with the potential to persist across generations.

Keywords: Methylation, endophytes, cross-kingdom communication

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NANOPRIMING AS AN EMERGING APPROACH IN PLANT BIOTECHNOLOGY

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Abstract

Increasing environmental stress from global climate change, such as drought, salinity, and temperature extremes, poses a major challenge to sustainable crop production. Developing strategies that help plants better avoid or cope with these stress conditions is therefore an important focus in modern plant biotechnology. One emerging approach is priming, which aims to enhance seed performance and early plant development under unfavorable conditions. This literature-based meta-analysis of recent studies investigates the effects of nanomaterials (NMs) used in seed priming. The goal was to identify general trends in how nanopriming influences germination, seedling growth, and stress tolerance. A range of NPs, including metal oxides (such as ZnO and TiO₂), carbon-based materials, and silica nanoparticles, have been tested across different plant species. Overall, most studies report positive effects at low concentrations, including faster germination, improved root and shoot development, and better resistance to abiotic stresses. These effects are often linked to enhanced water uptake, activation of antioxidant systems, and improved enzyme activity during early growth stages. However, the results are not always consistent. Some studies show neutral or negative effects at higher nanoparticle concentrations, highlighting the importance of dosage and particle type. There is also variability depending on plant species and experimental conditions. In conclusion, nanopriming shows strong potential as a tool for stress management in crops, but further standardized and field-based research is needed to confirm its practical application.

Keywords: Nanopriming, stress, plant biotechnology, nanomaterials, seed priming

FOREST SEED QUALITY TESTING AT THE CROATIAN FOREST RESEARCH INSTITUTE

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Abstract

The Laboratory for Testing Seed Quality (LIS), operating within the Croatian Forest Research Institute (CFRI), conducts scientific and professional activities in the field of forest seed science. Its work includes the analysis and control of forest seed quality in Croatia, performed in accordance with the Law on Forest Reproductive Material, with the aim of supporting the use of high-quality material in forestry practice. The CFRI acts as the official body responsible for the control of production, marketing, and quality testing of forest reproductive material in Croatia. Since 2006, LIS has been a member of the International Seed Testing Association (ISTA) and operates within the framework of CROLAB, the national laboratory network. Seed testing is conducted according to ISTA rules, ensuring standardized methods and international comparability of results. LIS carries out research on the morphological and physiological characteristics of forest tree seeds, as well as studies on seed yield and storage. Its professional activities include sampling and seed quality testing of seed lots. A wide range of analyses is performed, including moisture content, analytical purity, germination, viability, thousand-seed weight, and seed health status. These results support seed production, processing, and storage and contribute to the conservation of forest genetic resources and adaptation to climate change. The aim is to provide an overview of the laboratory's main activities, with an emphasis on the application of international standards and practical experience.

Keywords: Forest seed quality, seed testing, forest reproductive material

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MODULATED CYTOKININS AS A TOOL FOR IMPROVING PLANT STRESS TOLERANCE

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Abstract

Cytokinins are important phytohormones regulating plant growth and development. Their levels often decrease during abiotic stress to stop growth. If we exo- or endogenously increase cytokinin levels, stress tolerance will increase. Nevertheless, cytokinin levels are sensitively balanced in plants, and high levels are rapidly degraded, which is problematic when the stress begins with a delay. The problem of rapid cytokinin metabolism can be circumvented by using modified aromatic cytokinins that are not readily degraded and can be stored in cells for future use. In this study, we tested *meta*-topolin-9-(tetrahydropyran-2-yl)purine (mT9THP), which is a stable cytokinin derivative that releases active *meta*-topolin gradually, preventing the rapid deactivation. 10nM mT9THP was added into hydroponics to roots of 14-days-old rice (*Oryza sativa*) seedlings. Heat stress (45 °C, 6h) was applied 24 h after cytokinin application. Some plants were also acclimated by moderate temperature (37 °C, 2h, applied 4 h before heat stress). Samples were collected before and after heat stress with respective controls (no cytokinin, with cytokinin). The application of mT9THP mitigated stress strength. The response to cytokinin had similar characteristics to short acclimation. Acclimation alone led to the elevation of endogenous cytokinins, too. The best results in stress tolerance were achieved after a combination of cytokinin pre-treatment and acclimation, promoting the expression of stress markers, antioxidant enzymes, and increasing volatile organic compound emission in advance of heat stress. Cytokinin mT9THP has great potential to be used as a priming agent for seed priming, increasing stress tolerance, and accelerating plant growth at the beginning of seedling development.

Keywords: Acclimation, cytokinin derivatives, heat stress, phytohormones, rice

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NANOPRIMING WITH PLANT-DERIVED ZNO NANOPARTICLES: CASE STUDY OF BROCCOLI AND LETTUCE MICROGREENS IN CONTROLLED ENVIRONMENT

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Abstract

Nanopriming with metal oxide nanoparticles is an innovative strategy to enhance crop yield and nutrition in modern agriculture. To achieve a sustainable and cost-effective way of using this technology, plant-derived green-synthesized nanoparticles are frequently applied. These types of nanoparticles (NPs) not only contain the pure metal oxide but also their nano corona can contain biomolecules, influencing crop yield and nutrition as an added value. At the same time, this nano corona raises some questions about their efficient application. In our study, two different plant species (*Hedera helix* and *Parthenocissus tricuspidata*) were used for green synthesis of ZnO NPs. Broccoli and lettuce microgreens grown in vertical LED light used greenhouse were treated with these NPs to investigate their effect as a priming agent. Based on our preliminary results, 50 mg L⁻¹ was chosen for experiments. Increased fresh weight was measured compared to the unprimed control plants, and in the case of broccoli, the green-synthesized NPs induced more biomass. Total chlorophyll levels increased in the case of broccoli but not in lettuce, without changing the ratio of chlorophyll a and chlorophyll b. Investigating the ascorbic acid (Asc) concentrations, we found that plant-derived ZnO NPs from both plant species were able to increase the Asc concentration in broccoli, but this was slight in the case of lettuce. Element analysis was also conducted, demonstrating that elements showed alterations when comparing the chemically synthesized and green-synthesized ZnO NPs in both microgreens. Our case study focuses on the significance of plant species-derived green synthesis of NPs, enhancing our knowledge about the applied nanotechnology in a controlled environment.

Keywords: nanopriming, green synthesis, microgreens, vertical farm

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METABOLOMICS-BASED INSIGHT INTO THE PHYSIOLOGICAL CONSEQUENCES OF SEED BIOPRIMING WITH *Priestia megaterium* IN RADISH MICROGREENS

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Abstract

Seed biopriming with plant growth-promoting rhizobacteria (PGPR) is a promising strategy to improve crop performance, yet its physiological consequences in functional foods remain insufficiently understood. Radish microgreens (*Raphanus sativus* L.) are valued for their high content of health-promoting secondary metabolites, particularly glucosinolates and polyphenols, which contribute to their antioxidant potential and nutritional quality. As our previous studies showed that seed biopriming with *Priestia megaterium*, combined with substrate inoculation in coconut substrate, significantly enhances the growth of radish microgreens, this study aimed to provide a metabolomics-based insight into the physiological consequences of this treatment. Metabolites were extracted using a modified Matyash method and analysed by ultra-high-performance liquid chromatography coupled with high-resolution tandem mass spectrometry (UHPLC-HRMS/MS). Key phytochemicals belonging to three main groups were selected for detailed evaluation: glucosinolates (e.g., glucoraphanin, glucobrassicin), phytohormones (e.g., salicylic acid, jasmonic acid), and phenolic compounds (e.g., sinapine, chlorogenic acid). Comparative analysis using one-way ANOVA revealed no statistically significant differences ($p > 0.05$) between control and treated plants in the levels of the investigated compounds. These findings indicate that *P. megaterium*-based seed biopriming promotes microgreens growth without significantly altering key metabolite pools. The results provide mechanistic support for seed biopriming as a sustainable strategy to improve radish microgreens production while preserving phytochemical quality and antioxidant potential.

Keywords: radish microgreens, PGPR bacteria, metabolomics, secondary metabolites, phytochemicals

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ANTI-PRIMING OF SUNDEW SEEDS: FUTURE INSIGHTS FROM PROTEOME PROFILING

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Abstract

Carnivorous plants are fascinating creatures occupying a specific ecological niche—a nutrient-deficient environment. Round-leaved sundew (*Drosera rotundifolia*) prefers sunny places on acidic soils, frequently inhabiting European peatlands. It forms numerous miniature seeds, which readily germinate under optimal conditions. However, germination on *Sphagnum* moss-based substrate, resembling the natural environment, is substantially lower. Therefore, we are exploring a potential inhibitory effect of *Sphagnum* water extracts of varying strengths on sundew seeds under different storage regimes. Proteome profiling will be done using reverse-phase liquid chromatography on Vanquish Neo and data-independent mass spectrometry on Orbitrap Exploris 240. Database search and label-free quantification will be done in FragPipe with the Dia-NN module, followed by statistical evaluation in Perseus. Bioactive secondary metabolites of sundew are used in numerous pharmaceutical applications. Consequently, a fine understanding of sundew reproductive biology is essential not only for ensuring the sustainability of its natural populations but also for enabling intensive cultivation.

Keywords: *Drosera rotundifolia*, moss extract, proteomics

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INFLUENCE OF GEOLOGICAL SUBSTRATE ON MORPHOLOGICAL AND PHYSIOLOGICAL TRAITS OF SELECTED PLANT SPECIES

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Abstract

This study examines the morphological and physiological variation in two plant species, *Thymus pulegioides* and *Plantago lanceolata*, collected from four ecologically distinct locations in Bosnia and Herzegovina. The sampling sites included limestone soils on Bjelašnica and Visočica, as well as ultramafic serpentine soils in Konjuh and Kladanj. The research aims to evaluate the impact of contrasting geological substrates on the plants' morphological traits and selected physiological characteristics. Morphological analyses involve measuring shoot lengths, as well as leaf length and width. The physiological assessments focus on quantifying photosynthetic pigments and total phenolics. Chlorophyll and carotenoid contents indicate photosynthetic efficiency, oxidative stress, and photoprotective responses, while phenolic compounds reflect antioxidant defence and adaptation to abiotic stress, including metal toxicity. Clear phenotypic and morphological differences between populations are evident, with visible leaf rubescence in the serpentine population, which may indicate stress-related accumulation of protective pigments such as anthocyanins, and slightly greater morphological characters on limestone soil. By comparing populations from limestone and serpentine habitats, this study highlights adaptive responses and intraspecific variability associated with different edaphic conditions. The data obtained can certainly improve our understanding of plant ecological adaptation and the potential role of substrate composition in shaping functional plant traits.

Keywords: edaphic adaptation; morphological variation; photosynthetic pigments; phenolic compounds.

BIOPRIMED *Silene sendtneri* AS A RHIZOSPHERIC FILTER FOR REDUCING CADMIUM TRANSFER IN TOMATO GROWN ON TWO DIFFERENT SOIL TYPES

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Abstract

Cadmium contamination in agricultural soils represents a major challenge for crop production, particularly because metal mobility and plant uptake strongly depend on soil properties and rhizosphere interactions. This study evaluated the potential of bioprimered *Silene sendtneri*, a cadmium-accumulating species, to modify cadmium dynamics and physiological responses of tomato (*Solanum lycopersicum* 'Micro Tom') grown on two different soil types. Tomato was cultivated in monoculture and in intercropping with *S. sendtneri* on peat substrate and Vertic Luvisol, under control and cadmium-supplemented conditions. Changes in soil metal concentrations, plant metal accumulation, bioaccumulation and translocation patterns, as well as stress-related metabolites, were assessed. The results showed that the effect of intercropping depended strongly on soil type. In peat soil, the presence of *S. sendtneri* contributed to reduced cadmium availability and altered the distribution of cadmium and essential micronutrients in tomato tissues. In Vertic Luvisol, higher soil buffering capacity moderated cadmium mobility, while intercropping influenced the retention and redistribution of iron, zinc, manganese, and cadmium within the soil-plant system. Bioaccumulation and translocation factors indicated that bioprimered *S. sendtneri* may function as a rhizospheric filter, reducing cadmium transfer toward tomato shoots depending on soil type and cadmium treatment. Changes in proline and soluble sugar contents further suggested activation of adaptive stress responses in tomato grown in intercropping systems. These findings highlight the importance of soil type in determining the efficiency of hyperaccumulator-crop intercropping and suggest that combining bioprimering with intercropping may represent a promising phytomanagement strategy for reducing cadmium transfer in tomato grown on Cd-affected soils.

Keywords: *Silene sendtneri*, tomato, cadmium, bioprimering, intercropping

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GQD NANOPRIMING MODULATES TOMATO RESPONSES TO DROUGHT, HEAT STRESS, AND THEIR COMBINATION

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Abstract

Drought and heat stress are major constraints to tomato cultivation, significantly reducing yield and causing substantial economic losses. Seed priming is a well-established pre-sowing strategy that enhances germination and stress tolerance by modulating physiological and molecular processes. In this context, carbon-based nanoparticles, particularly graphene quantum dots (GQDs), have emerged as promising tools to improve crop resilience and productivity under climate change. However, their role in regulating plant responses to abiotic stress remains insufficiently understood. This study aims to evaluate the effects of γ -GQD-based seed nanopriming on tomato (*Solanum lycopersicum* L., cv. Micro-Tom) under drought, heat stress, and their combined application, with a focus on plant fitness, redox regulation and antioxidative responses. Seeds were treated with two γ -GQD concentrations (300 and 500 mg/mL), alongside hydroprimed and untreated controls, and plants were subsequently exposed to 10 days of drought and short-term heat stress applied individually and in combination. Preliminary results indicate that γ -GQD-treated plants increased aboveground biomass, suggesting altered growth allocation under stress conditions. Furthermore, γ -GQD treatment influenced oxidative and antioxidant responses to drought and heat stress and was linked to changes in fruit carotenoid composition, including lycopene and β -carotene. Additionally, higher γ -GQD concentration was associated with earlier and more frequent fruiting under drought. Given their ability to modulate redox processes, including the generation of singlet oxygen ($^1\text{O}_2$), γ -GQDs represent a promising nanopriming strategy to enhance plant performance and mitigate the adverse effects of drought and heat stress.

Keywords: GQD nano-priming, Micro-Tom tomato, drought, heat stress, antioxidants, plant fitness

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SILICON SEED PRIMING ENHANCES TOMATO RESILIENCE TO COMBINED DROUGHT AND HEAT STRESS

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Abstract

The increasing frequency and intensity of drought and heat events under climate change pose a major threat to crop productivity, necessitating the development of effective, sustainable strategies to enhance plant stress resilience. Silicon (Si) application has emerged as a promising ecological approach to mitigate abiotic stress; however, the mechanisms by which Si-mediated seed priming enhances plant responses to drought and elevated temperature remain poorly understood. In this study, we investigated the effects of Si seed priming (0.5 mM) on tomato (*Solanum lycopersicum* L. cv. Micro-Tom) exposed to drought, heat stress, and their combination, with a focus on plant adaptation, redox regulation, and antioxidant responses. Hydroprimed and non-primed seeds were used as controls. Preliminary results showed that Si priming increased aboveground biomass without compromising plant height, indicating optimised growth efficiency and resource allocation under adverse conditions. Moreover, Si-treated plants exhibited modulated oxidative and antioxidant responses across all treatments, suggesting a role in fine-tuning reactive oxygen species homeostasis rather than simply reducing oxidative damage. Notably, Si priming was associated with shifts in fruit carotenoid composition and earlier, more frequent fruiting under drought, pointing to enhanced reproductive adaptation and improved stress acclimation. In conclusion, Si seed priming represents a practical, low-cost, and environmentally friendly strategy to alleviate the negative effects of drought and high temperature, enhancing stress tolerance and helping to maintain plant performance under adverse environmental conditions.

Keywords: Silicone, seed priming, Micro-Tom tomato, drought, heat stress, antioxidants

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SEED PRIMING UNIVERSALLY ENHANCES PLANT PERFORMANCE ACROSS LIFE STAGES, CROP TYPES AND STRESS ENVIRONMENTS: A GLOBAL META-ANALYSIS

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Abstract

Seed priming is widely adopted to improve crop establishment and stress resilience, yet the generality and biological drivers of its benefits across priming strategies, crop types, and environmental contexts remain poorly resolved. We conducted a global meta-analysis of 900+ independent studies identified by a systematic search of five databases spanning 374 plant species and 26 years of published research (2000–2026), to quantify the overall effect of seed priming on plant performance and identify the moderators of that effect. Using DerSimonian–Laird random-effects models on 7,213 effect sizes (log response ratio, lnRR), we found a significant universal positive effect (lnRR = 0.292 [95% CI: 0.276, 0.309]; $p < 0.001$), corresponding to a ~34% mean improvement in primed over control plants. A Jonckheere–Terpstra trend test confirmed a significant positive trend in priming benefits across biological organisation levels ($z = 4.01$, $p < 0.001$), with effects greatest at the biochemical and yield endpoints, germination (lnRR = 0.314), seedling growth (0.338), physiological responses (0.298), biochemical markers (0.409), and final crop yield (0.441). Among priming strategies, combined treatments (lnRR = 0.384) and nanopriming (0.316) were most effective. Hydropriming was the most conservative (0.164). Hormonal priming produced the strongest effects in industrial crops (lnRR = 0.515), while vegetable crops showed the weakest response to hydropriming (0.088). Salinity severity progressively attenuated priming efficacy ($\beta = -0.00192 \text{ mM}^{-1}$; $R^2 = 11.6\%$), whereas increasing drought intensity enhanced it ($\beta = +0.019$; $R^2 = 6.8\%$). Sensitivity analyses confirmed robustness across data sources and variance-imputation approaches (lnRR: 0.262–0.292). These findings establish that priming-induced benefits compound across the plant life cycle and are fine-tuned by crop physiology, priming chemistry, and stress context.

Keywords: abiotic stress, crop yield, global meta-analysis, plant stress resilience, seed priming

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BIOPRIMING AND CLIMATE CHANGE: AN OVERVIEW

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Abstract

Exposure of crops to stress is the most significant obstacle to agricultural security and food production worldwide, and some of these stresses are caused by climate change. They cause different types of stress in plants through frequent occurrences such as drought, high temperatures, soil salinity and irregular rainfall, which negatively affects plants, i.e. their growth, development and yield. During their life cycle, plants go through various molecular, cellular and physiological changes in order to fight against various abiotic and biotic stresses. Modern agricultural production implies the application of various measures to mitigate the negative impact of abiotic and biotic factors in plants. One of them is biopriming, which is an ecological seed treatment before sowing that combines physiological hydration with biological inoculation (bacteria or fungi) in order to improve germination, increase seedling vitality and protect against pathogens, relieve stress, increase nutrient intake and stimulate plant growth. It is also a viable alternative to applying chemical seed treatments. This study provides an overview of existing scientific knowledge on the application of biopriming, with an emphasis on the role of microorganisms in the regulation of physiological and biochemical processes in plants. The mechanisms of action of biopriming are analyzed and its influence on increasing the tolerance of plants is considered. Understanding the mechanisms involved in seed biopriming by plant growth-promoting microbes is important for the effective use of this technique in sustainable agriculture. For its wider application, further research is needed, which would focus on the discovery of new types (strains) of microorganisms for use on different plants.

Keywords: Biopriming, climate change, microorganisms.

NATURAL SEED FILM COATING TECHNOLOGY FOR THE CONTROL OF DISEASES TRANSMITTED BY SEEDS

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Abstract

Seed is the most critical propagative material in crop production, and farmers consistently seek high-quality seed lots to maximize productivity and economic returns. Seed quality is influenced by numerous factors, and various seed-priming technologies have been developed. Seed coating has emerged as a promising technique for seed quality in the face of climate-induced stressors and provides an effective strategy for managing seed-borne diseases. Bacterial canker and wilt, caused by the seed-borne pathogen *Clavibacter michiganensis* subsp. *michiganensis* (Cmm), is one of the most destructive diseases affecting tomato production worldwide. This study presents key scientific findings on the use of natural seed film-coating technology to control seed-transmitted pathogens. Certified pathogen-free tomato seeds (cv. Rio Grande) were artificially inoculated with Cmm (1.8×10^8 CFU/mL) and subsequently film-coated with varying concentrations (250–1000 ppm) of essential oils extracted from *Origanum vulgare*, *Thymus vulgaris*, *Lavandula officinalis*, and *Rosmarinus officinalis*. Multiple disease-related and seed-quality parameters were evaluated both in vivo and in vitro. The results demonstrated that *O. vulgare* essential oil was the most effective treatment in suppressing Cmm. Consequently, a novel method for controlling seed-borne disease was developed and patented through the Turkish Patent and Trademark Office (TÜRK-PATENT).

Keywords: Seed Priming, Climate Change, Seed Film Coating, Seedborne Disease, Essential Oil

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INFLUENCE OF BIOSTIMULANT SEED PRIMING ON GERMINATION OF CHIVES (*Allium schoenoprasum* L.)

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Abstract

This study aimed to evaluate the effect of the biostimulant Radifarm on seed germination, germination energy, root length, seedling height, and biomass of chives (*Allium schoenoprasum* L.). Chives are a perennial spice species from the Alliaceae family, commonly grown in small-scale home production. Seed germination is influenced by environmental factors such as temperature, moisture, light, and oxygen. Biostimulants are widely used in seed treatment to improve germination performance, overcome seed dormancy, and enhance early plant development under suboptimal conditions. Radifarm contains organic matter, polysaccharides, peptides, free amino acids, vitamins, and chelated zinc, and it promotes root initiation, lateral root development, and plant recovery from stress conditions. The experiment was conducted in 2025 at the Seed and Planting Material Certification Laboratory, Institute of Horticulture, Faculty of Agriculture, University of Banja Luka. The experiment was set up in Petri dishes with filter paper moistened with distilled water (control) or Radifarm solution (treatment), using a total of 400 seeds obtained from vegetatively propagated plants (clump division). Results showed that Radifarm had a statistically significant effect on most measured parameters. Germination energy in the treated group was 28.57% higher than in the control. Seed germination was 47.37% higher than the control. Seedling height was 2.48 cm, which was 12.21% higher than the control. Root length reached 1.67 cm, which was 65.35% higher than the control. No statistically significant differences were observed in fresh and dry biomass between treatments, although higher mean values were recorded in the Radifarm treatment. In conclusion, Radifarm improved germination and early seedling growth of low-vigor seeds, indicating its potential to enhance establishment and stress tolerance in chives.

Keywords: biostimulants; seed priming; chives (*Allium schoenoprasum* L.); germination; stress tolerance

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HARNESSING SILICON FOR ENHANCING PLANT RESILIENCE: A SUSTAINABLE APPROACH TO MITIGATE BIOTIC AND ABIOTIC STRESSES

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Abstract

Climate change is accelerating biotic and abiotic stresses, posing a serious threat to global agricultural productivity. Silicon (Si) has gained significant attention for its ability to enhance plant resilience under adverse environmental conditions. Si plays a key role in mitigating stress by regulating biochemical pathways, reinforcing structural integrity, and reducing oxidative damage through controlled reactive oxygen species (ROS) production. Exogenous Si application strengthens plant antioxidant defenses, stabilizes cell membranes, and improves water-use efficiency, enabling crops to better withstand drought, salinity, and pathogen attacks. Biofortification strategies facilitate Si accumulation in plant tissues, further enhancing stress tolerance and crop quality. The identification of Si transporter genes and advancements in genetic engineering present new opportunities to modulate Si uptake, improving plant defense mechanisms while minimizing the use of chemical pesticides, herbicides, and fungicides. Si-induced modifications in plant metabolism also contribute to enhanced nutrient uptake, improved photosynthetic efficiency, and better growth under challenging environmental conditions. Understanding the physiological and molecular mechanisms of Si-mediated stress resistance can help optimize its application in sustainable agriculture. Integrating Si-based strategies in crop production systems can significantly enhance yield, quality, and overall resilience against climate-induced stressors, making it a promising solution for global food security.

Keywords: Silicon, climate change, plant resilience

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POLYHYDROXYALKANOATES: EXTRACTION FROM BIOMASS AND APPLICATION IN SEED IMPROVEMENT

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Abstract

Polyhydroxyalkanoates (PHA) are biodegradable and biocompatible polyesters derived from various mixed microbiological cultures (MMC). The PHA molecule consists of monomeric units (R)- hydroxy fatty acids, interconnected by an ester bond; each monomer unit has R group in the side chain. The particular advantage of these biopolymers is reflected in their availability in various waste streams that are rich in carbon and nutrients. In our study, we extracted PHA from sewage sludge. Sludge is a biomass rich in organic matter and different bacterial consortia, among which are PHA-producing bacteria. Extraction was performed with chloroform solvent at 50°C, after which surfactant was added to remove non-PHA cells. We used less harmful surfactants such as non-ionic Tween 80 and biodegradable Glucopon. The produced polymers were subjected to FT-IR analysis, the results showed spectra characteristic of polyhydroxyalkanoates, respectively, the ester carbonyl band (C=O) at 1733.93 cm⁻¹. Also, DTG analysis of the polymer showed a thermal stability corresponding to PHA, with a temperature range of 250-300°C. Thanks to their physicochemical properties, PHA finds various applications in industry and agriculture, replacing petroleum-based plastics. Biopolymers, including PHA, are effective in many studies as seed improvers. They can potentially act as carriers of functional agents and delivery of microbes that would contribute to seed quality and resistance, acting as plant biostimulants. PHAs are used for encapsulation of fertilizers and other harmful substances, which makes them promising materials in agriculture. Directions of our future research will focus on the real application of PHA in planting crops, as their role in improving seed quality has been determined in detail.

Keywords: Polyhydroxyalkanoates, biomass, sludge, seed, improvement

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