

Thesis of a Doctoral (PhD) Dissertation

**ROLE OF PLANT PROTECTIVE AGENTS IN THE ALLEVIATION OF
VARIOUS ABIOTIC STRESSES IN CROP PLANTS**

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1. Introduction

Crop productivity is increasingly challenged by abiotic stresses such as drought, soil salinity, heat, and cold, which significantly impact both the quantity and quality of agricultural output (Bashir et al., 2019). Climate change projections predict exacerbation of these challenges, with the global population expected to rise from approximately 8 billion today to an estimated 9.7 billion by 2050 (United Nations, 2023). As arable land faces increasingly adverse conditions (Cramer et al., 2011), mitigating the effects of these stresses on agriculture is crucial.

Abiotic stresses can reduce crop yields by up to 60% compared to optimal conditions (Boyer, 1982). The growing frequency of climatic shifts, especially in polar regions, underscores the importance of understanding and mitigating their impact on global agriculture (Zhang et al., 2022). Recent studies using advanced machine-learning algorithms report that climate extremes influence up to 50% of the variability in crop yields worldwide (Vogel et al., 2019). Such shifts increase exposure to floods, coastal erosion, desertification, and food insecurity (Fatima et al., 2020).

Addressing these challenges requires immediate, collaborative action. The scientific community plays a vital role in developing strategies to identify climate-resilient crops, optimize resource use, and explore plant protective agents that enhance stress tolerance and provide essential nutrients. This research focuses on investigating various plant protective agents and light quality interactions to enhance crop stress tolerance, specifically under water deprivation conditions.

1.2 Objectives

This research aims to explore the role of plant protective agents' acetic acid, melatonin, and spermine and light quality in mitigating the effects of water deprivation on crops. The objectives include:

1. Investigating the impact of acetic acid, melatonin, and spermine on crop stress tolerance under water deprivation.
2. Examining the effect of light quality in general and under water deprivation to identify innovative strategies for improving crop resilience.
3. Providing insights that could contribute to developing more resilient crops and sustainable farming practices in the face of environmental pressures.

2. Materials and Methods

2.1 Experimental Design: Plant Material and Treatment Patterns

Between 2021 and 2024, experiments were conducted at the Institute of Crop Sciences, Department of Applied Plant Biology, University of Debrecen, Hungary. The studies were performed in a controlled climate room utilizing hydroponic systems. Optimal growth conditions were maintained with 65-75% relative humidity, a 16/8-hour light/dark cycle, temperatures ranging from 24°C during the day to 20°C at night, and light intensity of 300 $\mu\text{mol m}^{-2}\text{s}^{-1}$. Plants were provided with a modified Hoagland solution as a nutrient source, replenished every three days (Marschner et al., 1990).



Figure 1. Sweet corn and spinach plants grown under controlled climate room

In the first experiment, three sweet corn genotypes Messenger, GSS 8529, and Tyson were grown hydroponically to the early vegetative stage (Zadoks scale 13-14) and subjected to water deprivation using 5% polyethylene glycol (PEG 6000). On the 25th day after sowing foliar treatment with acetic acid at two different concentrations (10 mM and 20 mM) was given for five consecutive days. After the 30th day of sowing non-destructive parameters were recorded, and the plants were harvested on the 35th day after sowing to analyze morpho-physiological and biochemical parameters.

The second experiment involved four sweet corn genotypes Messenger, Dessert, Royalty, and Tyson grown hydroponically and subjected to 8% and 12% PEG for water deprivation at V4-V5 (Zadoks scale 14-15). Foliar treatment with 100 μM melatonin was given for seven days at the V6-V7 vegetative stage, with measurements taken at the V8-V9 (Zadoks scale 18-19) stages for various physio-morphological and biochemical parameters.

The third experiment utilized the same four sweet corn genotypes and followed a similar protocol, with water deprivation induced using 8% and 12% PEG and spermine applied via

foliar spray at 0.2 mM for seven days at the V6-V7 vegetative stage. After spermine treatment for one week at the V8-V9 vegetative stage (Zadoks scale 18-19), samples were taken to evaluate several morphological, photosynthetic, and biochemical parameters.

Additionally, spinach seeds (*Spinacia oleracea* var. Matador) were surface sterilized and exposed to 2.5% PEG to induce water deprivation. Germination parameters were monitored over seven days. Spinach seedlings were also grown under three different light qualities blue light, normal white light, and red light with UV-C flashes once a week to evaluate the effects of light quality on growth under optimal and water-deprived conditions.

2.2 Methodology

Germination traits were assessed through germination percentage, mean germination time (Ellis and Roberts, 1981), and germination rate (Ranal et al., 2009). Growth measurements included root and shoot lengths, root volume, fresh and dry weights, specific leaf area (Garousi et al., 2016), and relative chlorophyll content (Konica Minolta, Japan). Photosynthetic pigments were quantified using UV-VIS spectrophotometry and high-performance liquid chromatography (HPLC) (Moran and Porath, 1980; Wellburn, 1994; Mészáros et al., 1995). Stomatal conductance (Delta-T, UK) and chlorophyll fluorescence (Walz GmbH, Germany) were measured to evaluate photosynthetic capacity and efficiency (Kitajima and Butler, 1975; Schreiber et al., 1996). Stress responses were analyzed by measuring malondialdehyde content and peroxidase activity (Baryla et al., 2000; Roxas et al., 1997).

2.3 Statistical Analysis

Experiments were arranged in a completely randomized block design with three replications, each containing four plants. Data was analyzed using two-way analysis of variance (ANOVA) and Fisher's protected least significant difference (LSD) test with GenStat Release 12.1 in sweet corn experiments.

Germination experiments used a randomized complete block design with 30 seeds per replicate. Spinach experiments under different light qualities were similarly analyzed, with three replications per treatment. Differences between treatments were evaluated using SPSS (Version 26, IBM USA) with ANOVA and Tukey's Post Hoc test.

3. Results

3.1 Acetic Acid Application And Its Effects On Sweet Corn Genotypes

Under water deficit conditions, this research examined the effects of acetic acid's foliar application on three sweet corn genotypes (Messenger, Tyson, and GSS 8529). The results showed that acetic acid can reduce the adverse effects of water deprivation by improving many physiological and biochemical traits. In a genotype-dependent manner, acetic acid treatment improved root and shoot lengths, root volume, specific leaf area, chlorophyll content, photosynthetic efficiency, and antioxidant defense mechanisms.

Acetic acid application significantly affected root development in sweet corn genotypes under water deprivation. Foliar treatments with 10 mM and 20 mM acetic acid resulted in substantial increases in specific root length in the Tyson genotype, with enhancements of 152.2% and 131.2%, respectively (Table 1). This improvement in root growth is essential for better water and nutrient uptake, which is crucial under drought conditions.

Table 1. Effect of foliar spray of acetic acid on the specific root length (cm g⁻¹) of three sweet corn genotypes under water deprivation. Different small letters indicate significant differences ($p \leq 0.05$) among the treatments of each genotype, and different capital letters indicate significant differences ($p \leq 0.05$) among genotypes within each treatment.

Treatment	Genotypes		
	Messenger	Tyson	GSS 8529
Control	100.57 ^{aA}	80.08 ^{dB}	75.05 ^{aC}
10 mM acetic acid	97.78 ^{bA}	137.50 ^{aB}	64.62 ^{cC}
20 mM acetic acid	91.12 ^{cA}	99.99 ^{bB}	71.69 ^{bC}
5% PEG	46.11 ^{fA}	34.50 ^{eB}	35.84 ^{eB}
10 mM acetic acid + 5% PEG	49.85 ^{eB}	87.12 ^{cA}	32.15 ^{fC}
20 mM acetic acid + 5% PEG	69.59 ^{dB}	79.75 ^{dC}	38.85 ^{dA}

Acetic acid also enhanced photosynthetic efficiency, as demonstrated by increased chlorophyll content. Specifically, 10 mM acetic acid increased chlorophyll-a by 68.6% and chlorophyll-b by 146.6% in the Tyson genotype, while 20 mM acetic acid led to increases of 46.4% in chlorophyll-a and 114.7% in chlorophyll-b (Table 2). These results suggest that acetic acid enhances the plant's ability to capture light and convert it into energy, thus improving growth under water deficit.

Table 2. Effect of foliar spray of acetic acid on photosynthetic pigments (mg g^{-1}) of three sweet corn genotypes under water deprivation. Different small letters indicate significant differences ($p \leq 0.05$) among the treatments of each genotype, and different capital letters indicate significant differences ($p \leq 0.05$) among genotypes within each treatment.

Trait	Treatment	Messenger	Tyson	GSS 8529
Chlorophyll- a	Control	13.69 ^{aA}	12.95 ^{aB}	9.83 ^{aC}
	10 mM Acetic acid	12.17 ^{bA}	10.13 ^{cB}	11.81 ^{aA}
	20 mM acetic acid	10.14 ^{cB}	10.16 ^{cB}	12.49 ^{aA}
	5% PEG	12.50 ^{bA}	7.93 ^{dB}	12.38 ^{aA}
	10 mM acetic acid + 5% PEG	12.00 ^{bA}	13.37 ^{aA}	12.19 ^{aA}
	20 mM acetic acid + 5% PEG	12.47 ^{bA}	11.61 ^{bA}	11.75 ^{aA}
Chlorophyll- b	Control	5.89 ^{aA}	6.48 ^{aA}	2.93 ^{aB}
	10 mM Acetic acid	5.19 ^{abA}	3.32 ^{cB}	3.60 ^{aB}
	20 mM acetic acid	3.03 ^{cB}	3.156 ^{cB}	4.05 ^{aA}
	5% PEG	4.29 ^{bcA}	1.91 ^{dB}	3.98 ^{aA}
	10 mM acetic acid + 5% PEG	3.82 ^{bcA}	4.71 ^{bA}	3.95 ^{aA}
	20 mM acetic acid + 5% PEG	4.45 ^{abcA}	4.10 ^{bcA}	4.29 ^{aA}
Total carotenoids	Control	3.89 ^{aA}	2.09 ^{cB}	2.07 ^{aB}
	10 mM Acetic acid	2.39 ^{bA}	2.13 ^{cA}	2.41 ^{aA}
	20 mM acetic acid	1.92 ^{bB}	2.29 ^{bcA}	2.54 ^{aA}
	5% PEG	2.62 ^{bA}	3.25 ^{aA}	2.78 ^{aA}
	10 mM acetic acid + 5% PEG	2.50 ^{bA}	2.93 ^{abA}	2.64 ^{aA}
	20 mM acetic acid + 5% PEG	2.59 ^{bA}	2.49 ^{bcA}	2.58 ^{aA}

Acetic acid application reduced oxidative stress, as evidenced by decreased malondialdehyde (MDA) levels. At 10 mM, MDA levels decreased by 32.4% in Tyson, 10.4% in GSS 8529, and 10.7% in Messenger (Fig.2). The reduction in oxidative stress was even more pronounced at 20 mM, with decreases of 31.6% in Tyson, 9.7% in GSS 8529, and 10.6% in Messenger. This indicates that acetic acid effectively mitigates oxidative damage by enhancing the plant's antioxidant defenses, which is crucial for maintaining cellular integrity under water deprivation.

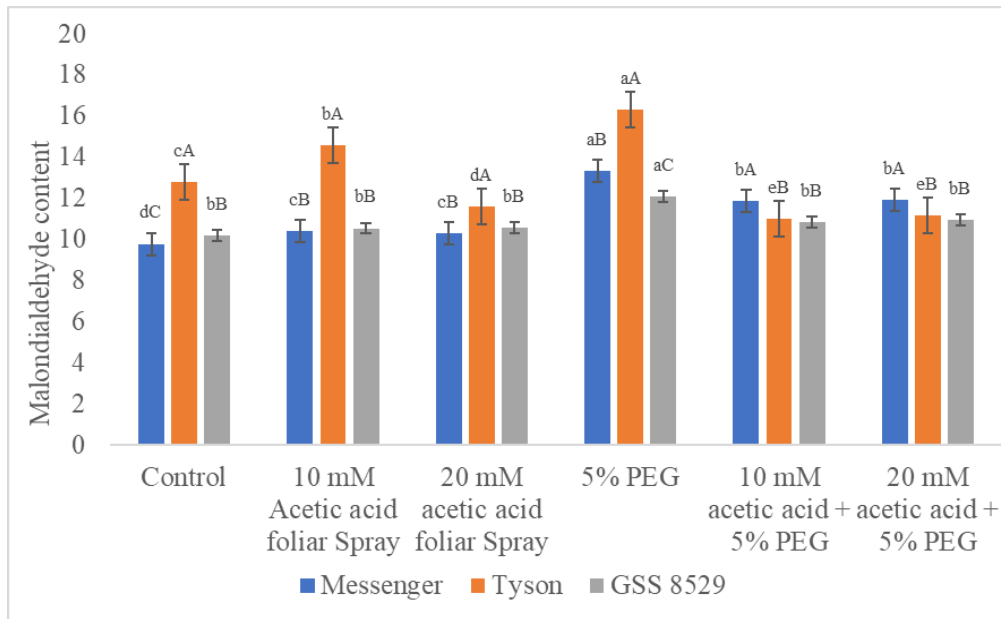


Figure 2. Effect of foliar spray of acetic acid on malondialdehyde content (nmol g⁻¹) of three sweet corn genotypes under water deprivation. Different small letters indicate significant differences ($p \leq 0.05$) among the treatments of each genotype, and different capital letters indicate significant differences ($p \leq 0.05$) among genotypes within each treatment.

These results indicate that more studies on optimizing acetic acid concentrations for sweet corn genotypes should concentrate on maximizing stress resilience and growth performance. Field trials will validate the effectiveness of acetic acid under natural growing conditions, and its practical relevance in agricultural practices will be evaluated.

3.2 Melatonin Application And Its Effects On Sweet Corn Genotypes

The study focused on the effects of foliar application of melatonin on improving the resistance of sweet corn to water deprivation caused by polyethylene glycol. Four different genotypes were tested using two different polyethylene glycol (PEG) concentrations and melatonin treatment. The recorded results revealed that the application of melatonin effectively mitigates the adverse effect of water deprivation, resulting in enhancements in a range of morphological, physiological, and biochemical traits.

Melatonin (100 μ M) application significantly improved photosynthetic efficiency under water deprivation. Specifically, melatonin increased specific leaf area in Messenger and Tyson genotypes. Under 12% PEG, Tyson exhibited a 64.3% increase in actual photochemical efficiency ($\Delta F/F_m'$), demonstrating melatonin's capacity to enhance photosynthetic performance under water deprivation (Table 3).

Table 3. Effect of melatonin and PEG treatments on average $\Delta F/F_m'$ in various sweet corn genotypes. Different small letters indicate significant differences ($p \leq 0.05$) among the treatments of each genotype, and different capital letters indicate significant differences ($p \leq 0.05$) among genotypes within each treatment.

Trait	Treatment	Genotypes			
		Dessert	Messenger	Tyson	Royalty
$\Delta F/F_m'$	Control	0.75 ^{cA}	0.75 ^{cA}	0.84 ^{bcA}	0.76 ^{cA}
	100 μ M mel.	0.75 ^{cA}	0.75 ^{cA}	0.74 ^{bA}	0.78 ^{cA}
	8% PEG	0.66 ^{bB}	0.70 ^{bA}	0.70 ^{abA}	0.64 ^{bB}
	12% PEG	0.56 ^{aB}	0.63 ^{aA}	0.56 ^{aB}	0.53 ^{aB}
	8% PEG + 100 μ M mel.	0.76 ^{cA}	0.76 ^{cA}	0.75 ^{bA}	0.77 ^{cA}
	12% PEG + 100 μ M mel.	0.75 ^{cA}	0.77 ^{cA}	0.92 ^{cA}	0.77 ^{cA}

Melatonin also improved antioxidant defense mechanisms. Under 8% and 12% PEG, melatonin application increased peroxidase activity, which is crucial for reducing oxidative stress. The decreased MDA levels (Fig.3) and enhanced antioxidant enzyme activity indicate that melatonin bolsters the plant's ability to manage oxidative damage, thus enhancing stress tolerance. These findings underscore melatonin's potential as a tool for improving crop resilience in drought-prone regions.

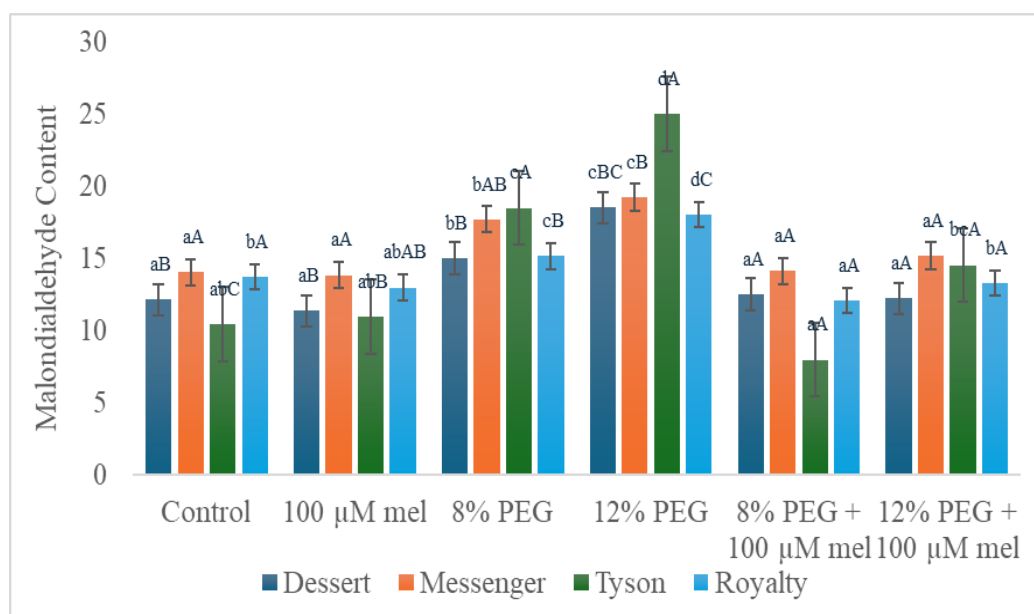


Figure 3. Effect of melatonin and PEG treatments on average malondialdehyde content (nmol g⁻¹) in various sweet corn genotypes. Different small letters indicate significant differences ($p \leq 0.05$) among the treatments of each genotype, and different capital letters indicate significant differences ($p \leq 0.05$) among genotypes within each treatment.

3.3 Spermine Application And Its Effects On Sweet Corn Genotypes

The research explored the impact of the foliar application of spermine on four sweet corn genotypes (Dessert, Messenger, Tyson, and Royalty) to reveal if it could enhance their capacity to tolerate water deficits. The results reveal that spermine (0.2 mM) significantly alleviates the adverse effects of water deprivation across various morphological and physiological traits, with notable genotypic variations in response.

Spermine application led to enhanced root and shoot lengths, with Tyson showing a 90.6% increase in shoot length under 12% PEG (Fig.4). These results indicate that spermine effectively promotes growth and improves resilience under water deficit.

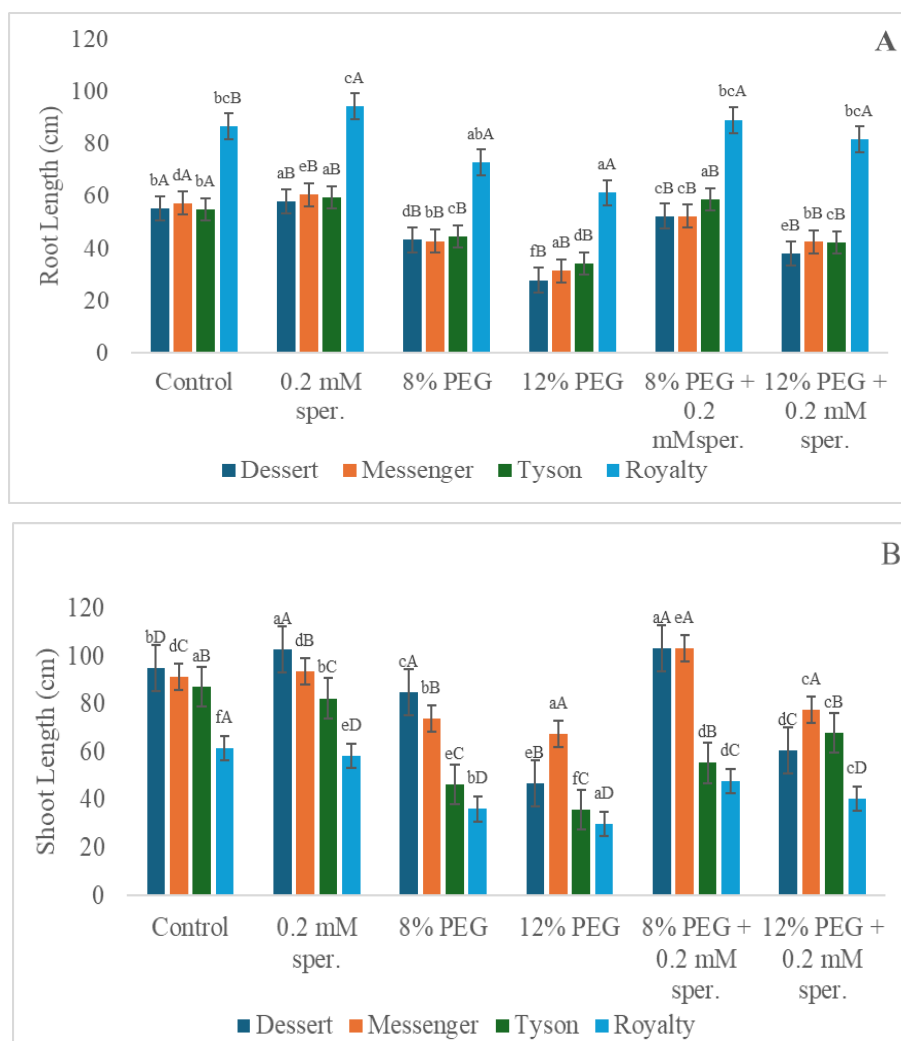


Figure 4. Effect of spermine and PEG-induced water deprivation on average root [A] and shoot [B] length (cm) on sweet corn genotypes. Different small letters indicate significant differences ($p \leq 0.05$) among the treatments of each genotype, and different capital letters indicate significant differences ($p \leq 0.05$) among genotypes within each treatment.

Spermine also improved photosynthetic performance and reduced oxidative stress. In Desert, MDA content decreased by 41.5% under 12% PEG (Fig.5) with spermine application, while Messenger exhibited a 327.5% increase in chlorophyll-b content. These findings suggest that spermine enhances photosynthetic efficiency and mitigates oxidative damage, contributing to better growth and productivity under water-limited conditions.

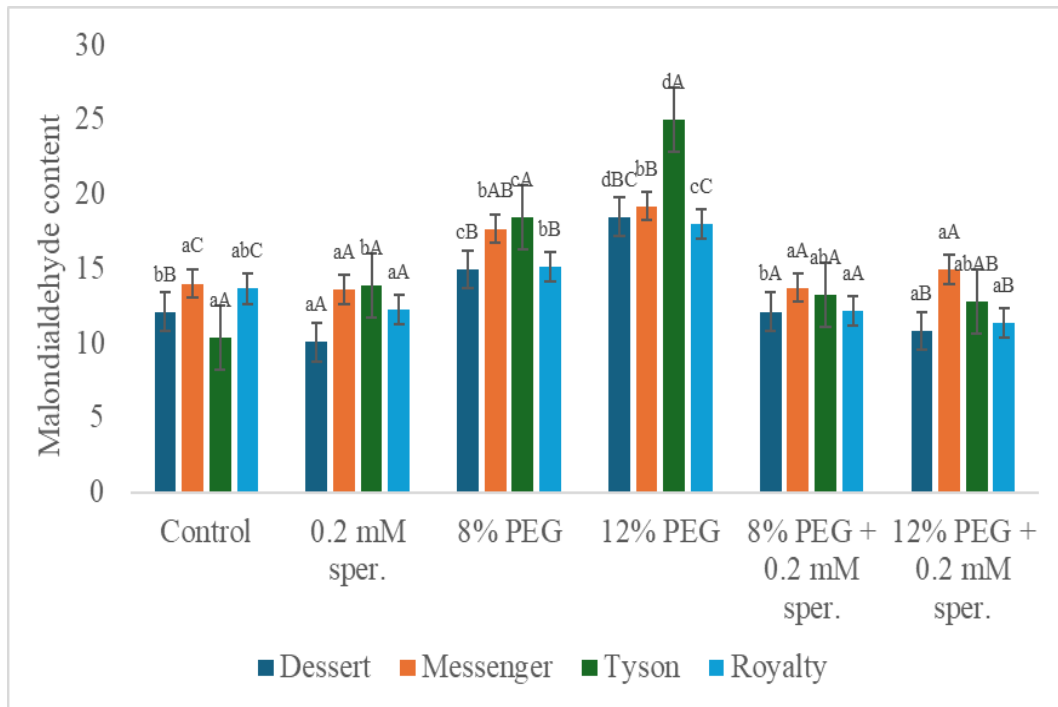


Figure 5. Effect of spermine on malondialdehyde content (nmol g⁻¹) in water deprived sweet corn genotypes. Different small letters indicate significant differences ($p \leq 0.05$) among the treatments of each genotype, and different capital letters indicate significant differences ($p \leq 0.05$) among genotypes within each treatment.

3.4 Effects Of Water Deprivation On Spinach Seed Germination

Water deprivation reduced spinach seed germination percentage from 79% to 63%, decreased mean germination time by 27.1%, and increased mean germination rate by 34.6% (Table 4). These results indicate that water deficit delays seed germination and affects seedling vigor, impacting plant establishment and growth.

Table 4. The effect of PEG-induced water deprivation on the various germination parameters of spinach seeds. Different letters indicate significant ($p \leq 0.05$). differences between treatments.

Traits	Treatments	
	Control	PEG
Germination percentage (%)	79.00 ^a	63.00 ^b
Mean germination time (day)	3.91 ^a	2.85 ^a
Mean germination rate(day ⁻¹)	0.26 ^a	0.35 ^a
Coefficient of variation of germination time (%)	52.07 ^a	42.61 ^a
Coefficient of velocity of germination (%)	26.28 ^a	35.69 ^a
Germination index (day)	9.06 ^a	8.52 ^a
Mean daily germination Percent (%)	11.27 ^a	9.04 ^b
Peak value for germination(day ⁻¹)	16.66 ^a	17.5 ^a
Germination value	194.2 ^a	159.3 ^a

3.5 Light Quality And Its Effects On Spinach plants Under Water Deprivation

Spinach grown under blue light (Light 1) demonstrated significant improvements in root volume and fresh root weight compared to plants grown under normal white light (Light 2) at full harvest (Table 5). Blue light also increased chlorophyll-a by 12% and total carotenoids by 18.1%. In contrast, exposure to red light combined with UV-C flashes (Light 3) severely impaired growth, reducing root length by 48.8% and fresh root weight by 95.7%. These findings suggest that blue light enhances growth and stress resilience, while red light combined with UV-C radiation is detrimental to plant growth.

Blue light improved spinach resilience to water deficit, enhancing both root and shoot development. In contrast, the negative impact of red light with UV-C exposure highlights the importance of managing light conditions to optimize plant growth and productivity in controlled environments.

Table 5. Effect of different light qualities on the growth parameters of spinach. Different letters among light qualities within a specific harvest indicate significant differences ($p \leq 0.05$).

Traits	First Harvest (25 th day after sowing)			Full Harvest (35 th day after sowing)		
	Light 1	Light 2	Light 3	Light 1	Light 2	Light 3
Root Length (cm)	33.8 ^b	45.6 ^a	23.3 ^b	30.4 ^a	35.7 ^a	39.1 ^a
Shoot Length (cm)	12.9 ^a	12.4 ^a	3.2 ^b	15.7 ^a	17.4 ^a	11.8 ^b
Root volume (cm ³)	6.58 ^a	6.1 ^a	0.3 ^b	33.6 ^a	17.5 ^b	7.8 ^a
Fresh root weight (g)	5.26 ^a	4.4 ^a	0.19 ^b	29.4 ^a	21.4 ^b	3.3 ^c
Fresh shoot weight (g)	6.77 ^a	5.8 ^a	0.38 ^b	20.5 ^a	19.5 ^a	5.6 ^b
Dry root weight (g)	0.23 ^a	0.1 ^a	0.01 ^b	0.71 ^a	0.6 ^a	0.5 ^a
Dry shoot weight (g)	0.60 ^a	0.4 ^b	0.04 ^c	1.83 ^a	1.9 ^a	1.36 ^a

4. New Scientific Results

1. Acetic Acid (10 mM & 20 mM) Foliar Spray

Acetic acid (10 mM and 20 mM) increased specific root length by 152.2% and 131.2%, respectively, in the Tyson genotype under water deficit; biomass improved by 41.9% in Messenger and 18.2% in GSS 8529 at 10 mM acetic acid; photosynthetic pigments in Tyson increased at 10 mM (Chl-a by 68.6%, Chl-b by 146.6%) and at 20 mM (Chl-a by 46.4%, Chl-b by 114.7%); MDA levels were reduced at 10 mM (by 10.7% in Messenger, 32.4% in Tyson, 10.4% in GSS 8529) and at 20 mM (by 10.6% in Messenger, 31.6% in Tyson, 9.7% in GSS 8529).

2. Melatonin (100 µM) Foliar Spray

Melatonin (100 µM) increased specific leaf area under PEG-induced stress (8% and 12% PEG) in Messenger and Tyson genotypes; improved actual photochemical efficiency by 64.3% in Tyson under 12% PEG; enhanced antioxidant activity by increasing peroxidase levels and reducing MDA content under both 8% and 12% PEG conditions.

3. Spermine (0.2 mM) Foliar Spray

Spermine (0.2 mM) increased root and shoot lengths across all genotypes, with Tyson showing a 90.6% increase in shoot length under 12% PEG; reduced oxidative damage, as seen by a 41.5% decrease in MDA content in Dessert under 12% PEG; significantly boosted chlorophyll-b content by 327.5% in the Messenger genotype under 12% PEG

4. Impact of Light Quality on Plant Growth

Blue light (Light 1) significantly promoted root volume and fresh root weight in spinach, enhancing overall plant growth. In contrast, red light combined with UV-C radiation (Light 3) severely inhibited growth parameters, including root and shoot lengths and biomass. The combination of Light 3 and 2.5% PEG-induced water stress proved fatal to the plants.

5. Practical Utilization Of Results

1. The results indicate that using foliar acetic acid can be a viable approach to enhance the ability of sweet corn to withstand water deprivation via increased crop output and the plant's ability to tolerate stressful conditions. Tailoring treatments based on specific genotypes maximize development by improving photosynthetic efficiency and enhancing antioxidant defenses to minimize oxidative damage. The foliar acetic acid application provides a cost-efficient and environmentally friendly approach to enhance resistance to water deprivation. Field applications should optimize the concentration of acetic acid by considering the genotype.
2. Acetic acid at both concentrations (10 mM and 20 mM) had beneficial effects in alleviating the negative consequences of water deprivation. However, the concentration of 10 mM in genotype Tyson often yielded comparable outcomes in terms of specific root length, specific shoot length, root volume, chlorophyll content, and oxidative stress indicators, particularly when used in conjunction with 5% PEG. This concentration also exhibited a consistent defensive reaction across several genotypes in the presence of water deprivation. Hence, the 10 mM acetic acid concentration may be the optimal and well-rounded option for improving the potential of sweet corn to withstand water scarcity.
3. Foliar application of melatonin can be utilized in agricultural practices to improve crop resilience, particularly in water deficit areas. All four genotypes (Messenger, Dessert, Royalty, and Tyson) reflect improved resilience to water deprivation when treated with melatonin (100 μ M). The study suggests that these genotypes are suitable for cultivation, especially in water-deficit environments, with the application of melatonin to enhance stress tolerance.
4. Foliar application of 0.2 mM spermine significantly enhances stress tolerance in sweet corn genotypes by mitigating the adverse effects of PEG-induced water deprivation. The results suggest that spermine can be effectively used to enhance crop resilience and productivity in water-limited environments, making it a valuable addition to agricultural practices, particularly in controlled hydroponic systems making hydroponic farming more resilient to environmental stressors.
5. Under LED lamps, improving the growth and quality of spinach plants requires optimized light qualities, ensuring a balanced blue-to-red ratio, and avoiding exposure to harmful UV-C radiation. Using tools such as SPAD meters and

spectrophotometry, farmers can effectively monitor relative chlorophyll content and photosynthetic pigments to make precise adjustments to lighting and watering in controlled environment agriculture settings, like vertical farming and hydroponics to control environmental factors effectively and consistently produce high-quality spinach.

6. References

1. *Bashir K. – Matsui, A. – Rasheed, S. – Seki, M.:* 2019. Recent advances in the characterization of plant transcriptomes in response to drought, salinity, heat, and cold stress. *F1000Research*. 8.
2. *Boyer J. S.:* 1982. Plant productivity and environment. *Science*. 218.4571: 443-448.
3. *Cramer G. R. – Urano, K. – Delrot, S. – Pezzotti, M. – Shinozaki, K.:* 2011. Effects of abiotic stress on plants: a systems biology perspective. *BMC plant biology*. 11: 1-14.
4. *Fatima Z. – Ahmed, M. – Hussain, M. – Abbas, G. – Ul-Allah, S. – Ahmad, S. – Ahmed, N. – Ali, M. A. – Sarwar, G. – Haque, E. U. – Iqbal, P.:* 2020. The fingerprints of climate warming on cereal crops phenology and adaptation options. *Scientific Reports*. 10.1: 18013.
5. *Garousi F. – Veres, S. – Bódi, É. – Várallyay, S. – Kovács, B.:* 2016. Assessment and comparison of selenium-enriched maize with sodium selenite and sodium selenate. *Acta Agraria Debreceniensis*. 68: 11-15.
6. *Kitajima M. B. W. L. – Butler, W. L.:* 1975. Quenching of chlorophyll fluorescence and primary photochemistry in chloroplasts by dibromothymoquinone. *Biochimica et Biophysica Acta (BBA)-Bioenergetics*. 376.1: 105-115.
7. *Marschner H. – Oberle, H. – Cakmak, I. – Römheld, V.:* 1990. Growth enhancement by silicon in cucumber (*Cucumis sativus*) plants depends on imbalance in phosphorus and zinc supply. *Plant and Soil*. 124: 211-219.
8. *Mészáros I. – Tóth, V. R. – Veres, S. – Váradi, G.:* 1995. Changes in leaf xanthophyll cycle pool and chlorophyll fluorescence of beech forest species and their sun/shade adaptation.
9. *Moran R. – Porath, D.:* 1980. Chlorophyll determination in intact tissues using N, N-dimethylformamide. *Plant physiology*. 65.3: 478-479.
10. *Ranal M. A. – Santana, D. G. D. – Ferreira, W. R. – Mendes-Rodrigues, C.:* 2009. Calculating germination measurements and organizing spreadsheets. *Brazilian Journal of Botany*. 32: 849-855.
11. *Roxas V. P. – Smith, R. K. Jr – Allen, E. R. – Allen, R. D.:* 1997. Overexpression of glutathione S-transferase/glutathione peroxidase enhances the growth of transgenic tobacco seedlings during stress. *Nature biotechnology*. 15.10: 988-991.

12. *Schreiber U. – Köhl, M. – Klimant, I. – Reising, H.:* 1996. Measurement of chlorophyll fluorescence within leaves using a modified PAM fluorometer with a fiber-optic microprobe. *Photosynthesis research*. 47.103-109.
13. United Nations.: 2023. Available at: <https://www.un.org> (Accessed: 29 November 2022).
14. *Vogel E. – Donat, M. G. – Alexander, L. V. – Meinshausen, M. – Ray, D. K. – Karoly, D. – Meinshausen, N. – Frieler, K.:* 2019. The effects of climate extremes on global agricultural yields. *Environmental Research Letters*. 14.5.054010.
15. *Wellburn A. R.:* 1994. The spectral determination of chlorophylls a and b, as well as total carotenoids, using various solvents with spectrophotometers of different resolution. *Journal of plant physiology*. 144.3: 307-313.
16. *Zadoks J. C. – Chang, T. T. – Konzak, C. F.:* 1974. A decimal code for the growth stages of cereals. *Weed research*. 14.6: 415-421.
17. *Zhang Y. – Li, Q. – Ge, Y. – Du, X. – Wang, H.:* 2022. Growing prevalence of heat over cold extremes with overall milder extremes and multiple successive events. *Communications Earth & Environment*. 3.1: 73.

7. Publications



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Subject: PhD Publication List

Candidate: Tahoora Batool Zargar
Doctoral School: Kálmán Kerpely Doctoral School
MTMT ID: 10084645

List of publications related to the dissertation

Foreign language international book chapters (1)

1. **Zargar, T. B.**, Basal, O., Veres, S.: Exogenous application of plant metabolites to enhance abiotic stress tolerance in plants.
In: Plant Secondary Metabolites and Abiotic Stress. Ed.: Ganesh C. Nikalje, Mohd. Shahnawaz , Jyoti Parihar , Hilal Ahmad Qazi , Vishal N. Patil , Daochen Zhu ISBN: 9781394185801

Foreign language scientific articles in Hungarian journals (2)

2. Ashraf, F., **Zargar, T. B.**, Veres, S.: Comparison Between Germinating Parameters of Basils (*Ocimum Basilicum* L.) and Pumpkin (*Cucurbita Pepo* L.) Under Drought Stress Conditions.
Rev. Agric. Rural Dev. 10 (1-2), 100-106, 2021. ISSN: 2677-0792.
DOI: <http://dx.doi.org/10.14232/rard.2021.1-2.100-106>
3. **Zargar, T. B.**, Ashraf, F., Veres, S.: Peg- Induced Drought Stress Effects on Spinach Germination Parameters.
Rev. Agric. Rural Dev. 10 (1-2), 126-132, 2021. ISSN: 2677-0792.
DOI: <http://dx.doi.org/10.14232/rard.2021.1-2.126-132>

Foreign language scientific articles in international journals (5)

4. **Zargar, T. B.**, Sobh, M., Basal, O., Veres, S.: Genotype-dependent resilience mediated by melatonin in sweet corn.
BMC Plant Biol. 25 (1), 1-14, 2025. EISSN: 1471-2229.
DOI: <http://dx.doi.org/10.1186/s12870-024-05972-y>
IF: 4.3 (2023)
5. **Zargar, T. B.**, Sobh, M., Basal, O., Janda, T., Pál, M., Veres, S.: Spermine driven water deficit tolerance in early growth phases of sweet corn genotypes under hydroponic cultivation.
Sci. Rep. 15 (1), 1-13, 2025. EISSN: 2045-2322.
DOI: <http://dx.doi.org/10.1038/s41598-025-86083-y>
IF: 3.8 (2023)





6. Basal, O., **Zargar, T. B.**, Veres, S.: Elevated tolerance of both short-term and continuous drought stress during reproductive stages by exogenous application of hydrogen peroxide on soybean.
Sci. Rep. 14 (1), 1-19, 2024. EISSN: 2045-2322.
DOI: <http://dx.doi.org/10.1038/s41598-024-52838-2>
IF: 3.8 (2023)
7. **Zargar, T. B.**, Basal, O., Veres, S.: Improving quality parameters of spinach by adjusting light spectra under moderate water deprivation conditions.
Not Bot Horti Agrobo. 51 (4), 1-17, 2023. ISSN: 0255-965X.
DOI: <http://dx.doi.org/10.15835/nbha51413325>
IF: 1.4
8. **Zargar, T. B.**, Mir, A. R., Alam, P., Hayat, S.: Melatonin Alleviates Cadmium-Induced Toxicity by Modulating Antioxidant Defence Mechanisms, Growth and Photosynthesis in Brassica juncea.
Russ. J. Plant Physiol. 69 (6), 1-10, 2022. ISSN: 1021-4437.
DOI: <http://dx.doi.org/10.1134/S1021443722060279>
IF: 1.4

List of other publications

Foreign language international book chapters (1)

9. Shahnawaz, M., Dar, R. A., Jeelani, S. M., **Zargar, T. B.**, Azhar, M. M., Ahmed, S., Ali, S., Chouhan, R., Sheikh, G., Gupta, P., Nautiyal, A. K., Sangale, M. K., Ade, A. B.: Botany, Geographical Distribution, Phytochemistry and Phytopharmaceutical Potential of *Rheum emodi* Wall. ex Meisn.: An Overview.
In: *Phytopharmaceuticals : Potential Therapeutic Applications*. Ed.: by Durgesh Nandini Chauhan and Kamal Shah, Wiley-Blackwell, Hoboken, 331-346, 2021. ISBN: 9781119681915

Foreign language scientific articles in Hungarian journals (1)

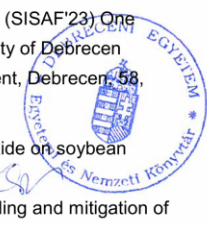
10. Sobh, M., **Zargar, T. B.**, Basal, O., Veres, S.: Evaluation of chickpea (*Cicer arietinum* L.) in response to salinity stress.
Agrártud. közl. 2023 (1), 105-110, 2023. ISSN: 1587-1282.
DOI: <http://dx.doi.org/10.34101/actaagrar/1/12274>





Foreign language abstracts (12)

11. Basal, O., Sobh, M., **Zargar, T. B.**, Serafin-Andrzejewska, M., Lejman, A., Kozak, M., Sowiński, J., Veres, S.: Evaluating some morphological traits of 3 chickpea varieties under rainfed conditions in Debrecen, Hungary.
In: 59th Croatian & 19th International Symposium on Agriculture : Book of Abstracts / Klaudija Carović-Stanko, Kristina Kljak, University of Zagreb Faculty of Agriculture, Zagreb, Croatia, Dubrovnik, 134-134, 2024, (ISSN 2459-5551)
12. Sobh, M., **Zargar, T. B.**, Dilo, A. M., Basal, O., Ayman, S. O., Veres, S.: Physiological and biochemical mechanisms of salt tolerance in chickpea genotypes.
In: 1st International e-Conference on Agro-Environmental Sustainability : Abstract Volume, University of Zagreb Faculty of Agriculture, Zagreb, 53, 2024. ISBN: 9788198115133
13. Basal, O., Sobh, M., **Zargar, T. B.**, Veres, S.: Preliminary report on possible sustainable utilization of chickpea as a second crop in Hungary: Influence of sowing date and supplemental irrigation.
In: 1st International e-Conference on Agro-Environmental Sustainability : Abstract Volume, University of Zagreb Faculty of Agriculture, Zagreb, 49, 2024. ISBN: 9788198115133
14. **Zargar, T. B.**, Basal, O., Veres, S.: Acetic acid as drought alleviator in different genotypes of sweet corn.
In: 58th Croatian & 18th International Symposium on Agriculture : Book of Abstracts. Ed.: Klaudija Carović, Stanko Ivan Širić, University of Zagreb Faculty of Agriculture, Zagreb, 141, 2023, (ISSN 2459-5551)
15. **Zargar, T. B.**, Sobh, M., Basal, O., Veres, S.: Drought Stress and Hydrogen Peroxide Mediated Responses in Spinach (*Spinacia oleracea* L.).
In: Sustainable and Innovative Solutions in Agriculture and Food Industry (SISAF'23) One Health approach. Eds.: Veres Szilvia, Kocsisné Papp Mariett, University of Debrecen Faculty of Agricultural and Food Sciences and Environmental Management, Debrecen, 69, 2023. ISBN: 9789634905356
16. Sobh, M., **Zargar, T. B.**, Basal, O., Veres, S.: Effect of NaCl-induced Salinity Stress on Some Morpho-Physiological and Biochemical Traits of Two Chickpea (*Cicer arietinum* L.) Genotypes under Hydroponic Conditions.
In: Sustainable and Innovative Solutions in Agriculture and Food Industry (SISAF'23) One Health approach. Szerk.: Veres Szilvia, Kocsisné Papp Mariett, University of Debrecen Faculty of Agricultural and Food Sciences and Environmental Management, Debrecen, 58, 2023. ISBN: 9789634905356
17. Basal, O., **Zargar, T. B.**, Veres, S.: Exogenous application of hydrogen peroxide on soybean elevated tolerance of short-term drought stress during flowering stage.
In: Biotechnology for a circular bioeconomy: carbon capture, waste recycling and mitigation of global warming: Programme and abstract book





18. Basal, O., Sobh, M., **Zargar, T. B.**, Sowiński, J., Serafin-Andrzejewska, M., Lejman, A., Kozak, M., Veres, S.: Inoculation Enhanced morpho-physiological Traits of Chickpea Genotypes in Debrecen, Hungary.
In: Sustainable and Innovative Solutions in Agriculture and Food Industry (SISAF'23) One Health approach. Szerk.: Veress Szilvia, Kocsisné Papp Mariett, Stündl László, Debrecen, 34, 2023. ISBN: 9789634905356
19. Basal, O., **Zargar, T. B.**, Veres, S.: Physiological responses of drought-stressed soybean to exogenous hydrogen peroxide application.
In: 58th Croatian & 18th International Symposium on Agriculture : Book of Abstracts. Ed.: Klaudija Carović, Stanko Ivan Širić, University of Zagreb Faculty of Agriculture, Zagreb, 131, 2023, (ISSN 2459-5551)
20. Basal, O., **Zargar, T. B.**, Veres, S.: Exogenous hydrogen peroxide alleviates severe drought stress effects on soybean morpho-physiology.
In: 19th Wellmann International Scientific Conference : Book of abstract. Ed.: Kiss Orsolya, University of Szeged Faculty of Agriculture, Hódmezővásárhely, 25, 2022. ISBN: 9789633068601
21. **Zargar, T. B.**, Basal, O., Veres, S.: Impact of different light intensities on spinach under drought conditions.
In: 19th Wellmann International Scientific Conference : Book of abstract. Ed.: Kiss Orsolya, University of Szeged Faculty of Agriculture, Hódmezővásárhely, 96, 2022. ISBN: 9789633068601
22. Veres, S., **Zargar, T. B.**, Basal, O.: Possibilities of Applying Protective Agents for Improving Stress Tolerance of Plants.
In: Biotechnology at The University of Debrecen - 2022 International Symposium : Abstract Book, [DE MÉK], [Debrecen], 67-67, 2022. ISBN: 9789634904687

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