

Thesis of Doctoral (PhD) Dissertation

**EFFECTS OF SILICON AND SULFUR FERTILIZATION ON ABIOTIC
STRESS RESISTANCE AND PRODUCTIVITY OF SPRING OAT (*Avena
sativa* L.) VARIETIES**

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1. INTRODUCTION AND OBJECTIVES

Agriculture is facing higher challenges during the last century, particularly regarding to the perspective of a fast-growing population. To address the scary food crises, agriculture has to evolve to sustain the food and feed demand for humans and animals. Therefore, the global trend continuous and extensive research are being conducted on cereal crop production to enhance yield performance and grain quality parameters. In order to eliminate food crises in the future the expansion of agricultural land is necessary and, the selection of the best performing varieties, as well as the implementation of best agricultural practices. A multidisciplinary approach is needed to challenge the food security for the human population, starting with genetic improvements, sustainable arable land management and technology adoption. In order to mitigate any risk in a global approach and supply sustainable food for upcoming generation, priority in agriculture production is paramount (Fróna et al., 2019).

Cereals are the most important crops for human diets, industrial processing and animal feeding. During the past 3 decades, the world highly produced cereal crops in this order: maize, rice, wheat, barley, sorghum and oat (*Avena sativa* L., *Zea mays* L., *Oryza sativa* L., *Triticum aestivum* L., *Hordeum vulgare* L., *Sorghum bicolor* L., and *Avena sativa* L.). Oats has a significant role in globally crop production, where around 10 million hectares are planted in recent years. Oats in the livestock industry provide a crucial feed for animals which can be used in different forms such as hay, green, and concentrated form. While oat flour or food products produced from it have a rich nutritional value that provides a very useful food in human diet (Loskutov et al., 2021).

There are several environmental stresses involving salt, chilling, and drought stress which can have different effect on plant growth and production. The stress effect is usually identified as a reduction in plant growth and photosynthesis, and this stress is connected with alternation in nitrogen and carbon metabolism. Nowadays the essential environmental stress is drought stress, which affects agricultural yield and productivity worldwide. Under rigorous water stress circumstances caused by drought or high salinity, the process of growing stops completely in plants, and all the solutes will be accumulated in crop cells (Barnabás et al., 2008), as well as temperature stress (Porter and Gawith., 1999) and nutritional stress.

Although plants can adjust to drought stress by their physiological, morphological, and metabolic means, external agronomic interventions are inevitable.

Soil nutritional parameters due to climatic conditions are resulting in potential mineral matrix changes where the weather tolerant minerals are accumulated. Furthermore, soil fertility functions are being degraded, and reliance on external nutrient inputs is expected to increase. It has been frequently stated that, the soil characteristics are being modified by the climatic variability. Soil based parameters, such as carbon content, even it is hard to modify can be verified by the scale of climatology, while fast response due to climatic variation can be detected in soil erosion specifically in precipitation measurements (Gelybó et al., 2018). It seems that the soil quality has an implication for food security due to ecosystem management. The main factors for the air, water, and heat management of soil profile are hydraulic conductivity, water retention, and soil composition. However, researchers have confirmed that stress of the soil moisture affects the soil parameters and crop production (Mills et al., 2014). This implies that exogenous application of any form of fertilizers into the soil could have a great role in both improving soil productivity and cereals' grain yield as well.

Yield potential depends on many factors such as growing area, cultivars, climatic conditions, and it is moderated by other factors such as stress tolerance and diseases, water, nutrient supply, agrotechnical factors, and the type of genotypes, which are the major factors for plant height and grain yield. Furthermore, there can be significant differences in productivity among oat varieties (Forsberg and Reeves., 1995).

Water is the major factor for oat development from seed germination to the last phase development and maturity, where the main factor for lower crop productivity it is drought stress. The yield potential is associated with available water and nitrogen supply. Under high water stress, the oats response to nitrogen is small, and the yield potential is low. While the water quantity increased, the response to the nitrogen also increased. Water stress has a high impact on reducing crop productivity, which makes the water vital component for crop growth from seed germination to the maturation phase, where the accurate amount of water is a basic requirement for water and soil management practices to increase agricultural production (Zhang et al., 2024).

Sulfur has a crucial role in the formation of vitamins, cysteine, methionine, sulpholipids, and proteins. Furthermore, sulfur application can improve the plant's growth and specifically the yield productivity (Narayan et al., 2023). Nutritional value and plant yield production are significantly influenced by the sulfur application (Aula et al., 2019).

The quality of spring oats in terms of macronutrients and micronutrients, yield or its physio-morphological characteristics are dependent on genetic factors, environmental conditions and foliar applications. To determine and clarify all of these factors, research was conducted where the influence of foliar fertilizers, environmental parameters and varietal divergences of spring oats were tested. Specific objectives were to:

- a) Evaluate the effect of sole and combined foliar treatment of silicon and sulfur on the physio-morphological parameters and yield of spring oat.
- b) Assess the impact of sole and combined foliar treatment of silicon and sulfur on the grain microelement and microelement concentration of spring oats.
- c) Assess the effect of varieties on the physio-morphological parameters, yield, and grain microelement and microelement concentration of spring oats.
- d) Analyze the effects of growing year and different environmental conditions on the physio-morphological parameters, yield, and grain microelement and microelement concentration of spring oat.

2. MATERIAL AND METHODS

2.1 Soil Parameters and the Experimental Location

The spring oat experiment was set up during the spring and summer seasons for three consecutive years from 2022 to 2024. The experimental location was set up in Hungary at Debrecen University with geographic coordinates 47°55'19" north latitude and 21°59'87" east longitude. At the beginning of March, before the first experimental sowing year in 2022, soil analysis was conducted, and the samples were carried out in 10 different soil layers with a depth interval of 20 cm for each layer. All the collected soil samples were analyzed at Debrecen University in the Agricultural Laboratory Centre.

Soil pH was measured in KCl, and in the first layer (0-20 cm) the measured pH was almost neutral (6.93), while in all the other layers it was slightly alkaline. K_A represents the Arany plasticity index type, which was between 45 and 49, representing a medium loam soil texture. The $CaCO_3$ amount in the top soil layers are lower, ranging from 0.52 - 1.97 while in subsoil layers reached a higher percentage, which showed the calcic horizon availability. The first layer (0-20 cm) is characterized with a good humus content 2.89 %, while in the other layers the humus content was decreasing. In the second layer (20 - 40 cm) it reached 2.89 % and in the last layer (180 - 200 cm) it was 0.41 %. Phosphorus showed the highest concentration in the 0 - 120 cm soil profile, with the greatest P_2O_5 (AL) content detected in the first layer (0 - 20 cm), reaching 1538 mg kg⁻¹. Potassium levels were relatively high in the first two layers (0 - 40 cm), ranging from 638 to 586 mg kg⁻¹. The NO_3^- (KCl) concentration ranged from 82.2 to 31.6 mg kg⁻¹ in the topsoil layers, while the highest nitrate concentration was recorded the 100 - 120 cm depth, where it reached 144 mg kg⁻¹. According to WRB (2022) soil system classification and compared to our analysis the land area in our experiment is Haplic Chernozem soil with Calcic Chernozem. The nutrient availability, uptake, and the root development capacity are well developed in our soil experiment, because spring oat roots mostly grow in the first three layers (0 - 60 cm) depth, and under the serious drought conditions, the maximum root growth can reach the (100 - 120 cm) layers.

2.2. Characterization of the crop years in the experimental years (Debrecen, 2022-2024)

The precipitation and temperature on a daily basis were measured by the Observatory Centre for Agrometeorological Precision Farming R&D Services, FAFSE, at the University of Debrecen in Hungary. The cultivation period of spring oats extends from March to July, while precipitation and temperature showed high variation both within and between growing seasons (Figure 1). The 2022 season the temperature was lower during the germination 5.2 °C, compared to the 2023 and 2024 seasons, with an average of 7.5-10 °C, respectively. Precipitation during the cultivation period also showed substantial differences both within and between growing seasons. The 2022 year was characterized by serious drought conditions while the lowest precipitation rate was detected during the March period with a total mean of 3.5 mm during that period. The cultivation season of 2023 was characterized by the best climatic conditions, where the highest amount of precipitation was during June, with a total average of 122.5 mm. The spring oats had a sufficient precipitation amount for their development at the final growing phenological phases. Furthermore, the climatic conditions during the 2024 cultivation seasons were highly variable during all the months. The highest precipitation was during the May period, which was significantly higher compared to the 2022 and 2023 growing seasons with a total higher average of 57.5% and 23.5%, respectively.

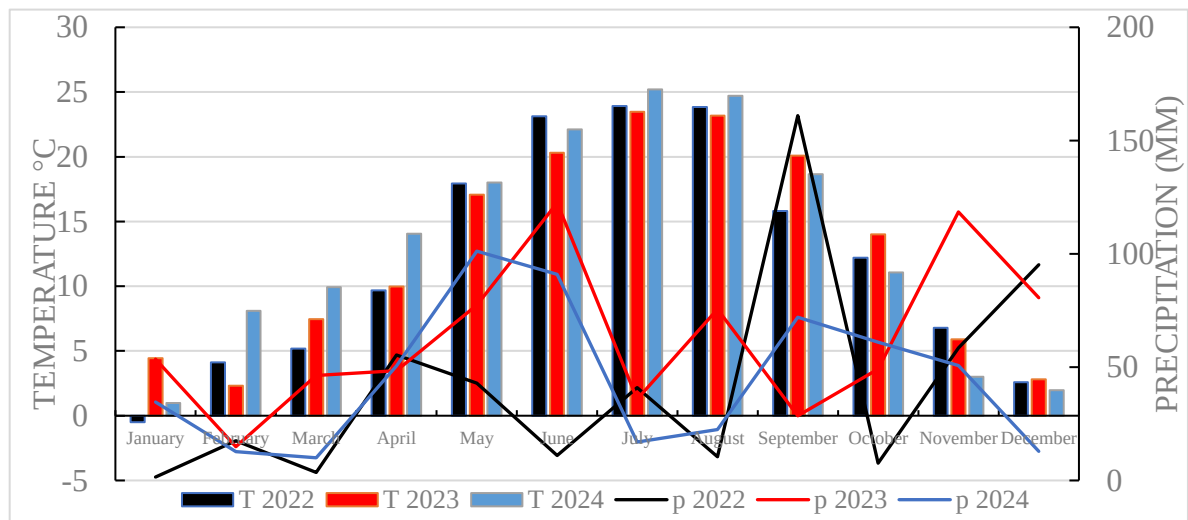


Figure 1: The monthly sum of precipitation and monthly mean of temperature during cultivation period for spring oats (Debrecen, 2022-2024).

The Pálfaí Drought Index (PaDI) was calculated to measure the water scarcity of the cultivation years for our experiment. Based on the Pálfaí and Herceg (2012) the PaDi index is measured following these steps:

$$PaDI_0 = \frac{\frac{\left[\sum_{i=apr}^{aug} T_i \right]}{5} * 100}{c + \sum_{i=oct}^{sept} (P_i * w_i)}$$

- **PaDI₀** represent the base drought index, which it is expressed in (°C 100 mm⁻¹).
- **T_i** represent the average monthly temperature for five months in a row April to August (°C).
- **P_i** refers to the total monthly precipitation measured from October to September (mm).
- **w_i** represent monthly weighting factor to calculate the PaDi index. The **w_i** values are as followed for calculated months: 0.1 for October; 0.4 for November – December; 0.5 for January – April; 0.8 for May; 1.2 for June; 1.6 for July; 0.9 for August and 0.1 for September.
- **c** present a constant value which is equal to 10 mm.

The drought index corrections factors (k_1 , k_2 , k_3) are calculated as it is presented bellow:

- a) **k_1** represent temperature correction factor

$$k_1 = \frac{(T_{jun} + T_{jul} + T_{aug})/3}{(\bar{T}_{jun} + \bar{T}_{jul} + \bar{T}_{aug})/3}$$

- $T_{jun} + T_{jul} + T_{aug}$ presenting annual temperature average for the June-August (°C).
- $\bar{T}_{jun}, \bar{T}_{jul}, \bar{T}_{aug}$ referring to 30 years average temperature (1991-2020) for June-August for period in (°C).

- b) **k_2** represents correction factor for precipitation

$$k_2 = \sqrt[4]{\frac{2 * \bar{P}_{summer}^{min}}{MIN(P_{jun}, P_{jul}, P_{aug}) + \bar{P}_{summer}^{min}}}$$

- $\bar{P}_{summer}^{min}$ referring to the lowest value from 30-years (1991-2020) precipitation sum of three summer months (June, July, August) in (mm).
- $MIN(P_{jun}, P_{jul}, P_{aug})$ representing the lowest value from annual precipitation sum of three summer months (June, July, August) in (mm).

- c) k_3 refereing the correction factor, for the precipitation circumstances of the previous period

$$k_3 = \sqrt[n]{\frac{\bar{P}}{\bar{P}_{36m}}}$$

- n present reduction factor, 3.0 on the plain area, on hilly or higher territories is 5.0 value.
- $\bar{P}$ refereing to mean of multi-annual precipitation sum for period October-September in (mm).
- $\bar{P}_{36m}$ presenting mean precipitation sum for period October-September for previous three years in (mm).

$$\bar{P}_{36m} = \frac{\sum_{i=(year-3)Oct}^{(year)Sept} P_i}{36}$$

- P_i refereing to monthly precipitation sum in (mm).

PaDI index calculation in ($^{\circ}\text{C } 100 \text{ mm}^{-1}$)

$$PaDI = PaDI_0 * k_1 * k_2 * k_3$$

2.3 Evaluation of the Drought Severity in the Experimental Years Based on Pálfai Drought Index

The modified Pálfai drought index (PaDI) is an excellent indicator for characterizing drought severity using a single numerical value across different agricultural years. The PaDI is computed using hydrological years (October–September) and integrates temperature data with weighted monthly precipitation totals. This drought index's main advantage lies in its simple calculation, which relies on readily available meteorological data (monthly average temperature, monthly sum of precipitation). The resulting value provides a reliable assessment of drought intensity and its potential impact on crop yields. (Table 1).

Based on the PaDI value, the year 2023 is classified as experiencing mild drought ($PaDI=4.3 \text{ }^{\circ}\text{C } 100 \text{ mm}^{-1}$), while 2024 is characterized as moderate drought ($PaDI=6.5 \text{ }^{\circ}\text{C } 100 \text{ mm}^{-1}$) The 2022 growing season is considered the most unfavorable, with a value of $11.6 \text{ }^{\circ}\text{C } 100 \text{ mm}^{-1}$, indicating a serious drought (Table2).

Table 1: The calculated Palfai Drought Index during three growing seasons in the experimental site in Debrecen (2022-2024).

Year	$P_{36 \text{ month}}$ mm	Monthly average P for previous 36 month mm	Sum of precipitati on April- August mm	$MIN(P_{jun},$ mm	$PaDI_0$ °C 100 mm ⁻¹	$PaDI$ °C 100 mm ⁻¹
2022	1519.7	42.2	160.9	10.5	8.75	11.6
2023	1567.3	43.5	359.8	35.9	3.76	4.3
2024	1761.7	48.9	282.2	17.0	5.19	6.5

Note: $P_{36 \text{ month}}$ = precipitation sum for period October-September for previous three years; $MIN(P_{jun}, P_{jul}, P_{aug})$ = the lowest value from annual precipitation sum of three summer months (June, July, August)

Table 2: Drought categories according to PaDI

$PaDI$ °C 100 mm ⁻¹	Classification
<4	droughtless year
4-6	mild drought
6-8	moderate drought
8-10	medium drought
10-15	serious drought
15-30	very serious drought
>30	extreme drought

2.4 The design and treatment of the spring oat experiment

The spring oat field experiment was established on small plots measuring 3x4 m (12 m²), using a randomized complete block design (RBCD). Eight varieties were sown in 3 m wide adjacent strips. Four treatments were arranged within four consecutive blocks, each containing three replications. The experiment has eight varieties, four treatments and three replications in total 96 plots. To maintain crop rotation, the experimental site within the Experimental Garden was relocated each year. The forecrops were wheat (2022), bean (2023)

and soybean (2024). The number of seeds were 550 seeds for square meter, and they were sowed in five centimeters depths in 18th March 2022, 7th March 2023 and 6th March 2024. NPK nutrients were applied as follows: N₅P₁₀K₃₀ kg ha⁻¹ in October 2021 and N₅₅ kg ha⁻¹ in March 2022; N₅₅ kg ha⁻¹ in March 2023; 2024). In the 2023 season, lodging occurred in some parts of our experiment due to favorable soil nutrient supply and optimal environmental conditions, including adequate water availability and legume preceding crops.

The analyzed spring oat (*Avena sativa* L) varieties were selected Hungarian varieties with promising productibility: Mv Kengyel, Lota, Mv Ménes, Panna, Mv Pehely, GK Kormorán, Mv Szellő, GK Pillangó.

The foliar treatments were in four blocks, where the first one was control (without fertilizer), the second block consisted of silicon foliar fertilization 0.5 L ha⁻¹, the third block was a sulfur fertilization 0.5 L ha⁻¹, and the fourth block was a combined silicon plus sulfur application 0.5 + 5.0 L ha⁻¹. The foliar nutrient applications were at the 300 L ha⁻¹ spraying volume and the foliar chemical compositions were:

- Sulfur: Jello Fluid commercial name with a chemical composition of high sulfur content in the lignosulfonate formulation 1000 g L⁻¹ SO₃, 30 g L⁻¹ N, 30 g L⁻¹ MgO, 27 g L⁻¹ B, 0.003 g L⁻¹ Mo
- Silicon: Optysil commercial name with a chemical composition of high content of silicon 200 g SiO₂ L⁻¹.

With the foliar treatments were used a nonionic adjuvant containing 60% dioctyl-sulfosuccinate sodium salt at a concentration of 0.025 %.

The spring oats were treated in three different phenological phases BBCH13 – three leaves unfolded, BBCH39 – flag leaf and BBCH73 – early milk phenological stages.

The plant protection was applied uniformly throughout the experiment. For the seed dressing tebuconazole was used, and for the pest control we applied lambda cyhalothrin in the amount of 150 mL ha⁻¹ at the end of tillering and end of flowering phases (BBCH29 and BBCH69). The pest control was specifically against the *Oulema melanopus* (spring oat leaf beetle).

2.5 Field measurements and data collection

Leaf area index (LAI) and normalized difference vegetative index (NDVI) data were collected from the selected spring oat leaves. Leaf area index (LAI) was determined using a LAI-2000 Plant Canopy Analyzer (LI-COR, Lincoln, NE, USA) operated in single-sensor mode, with both above- and below-canopy measurements taken using the same LAI-2050 optical sensor. For each plot, two above-canopy and eight below-canopy readings were recorded. The eight below-canopy measurements were averaged to obtain a representative LAI value for each plot. Normalized difference vegetation index (NDVI) was measured in the field using a hand-held Trimble Inc. GreenSeeker crop sensor. The sensor provides active illumination through light-emitting diodes (LEDs) at wavelengths of 656 nm and 774 nm. This two-band optical reflectance sensor records the intensity of reflected red and near-infrared (NIR) radiation to calculate the optical reflectance ratio. Measurements were initiated by pulling the trigger at the beginning of each plot, and multiple readings were collected across the sensing area. An average NDVI value was automatically calculated when the trigger was released at the end of the row. During measurements, the sensor was held at a constant height of 60 cm above the canopy to ensure reliable readings. NDVI and LAI measurements were performed weekly, beginning at the BBCH 13 phenological stage and continuing until the end of the growing season. Seven measurements were carried out during the growing season in 2022 and 2023, while eight measurements were taken in 2024.

The photosynthetic total conductance, transpiration, and assimilation rate were measured on intact leaves using a LI-6800 portable photosynthesis system (LI-COR, Lincoln, NE, USA). The instrument is equipped with two high-precision infrared gas analyzers that determine the mole fractions of CO₂ and H₂O in the air. Photosynthetically active radiation in the chamber was maintained at 1500 $\mu\text{mol photons m}^{-2} \text{ s}^{-1}$, with a spectral composition of 90% red light (625 nm) and 10% blue light (475 nm). The chamber CO₂ concentration was maintained at 400 $\mu\text{mol mol}^{-1}$. Measurements were performed on light-adapted leaves, with six readings taken per leaf on two plants from each plot. Photosynthetic parameters were measured at two-week intervals, starting in early May.

The harvesting was completed by using a Wintersteiger 125 plot combine with a 125 cm cutting width. The harvesting time was performed on the 11th July 2024, and 2022 and 24th

July 2023. Grain samples were taken from each harvested plot to determine grain moisture content, thousand kernels weight and grain quality parameters.

2.6 The grain element content analytical method

The grain quality analysis for the measurement of the elemental composition has been conducted were analyzed at Debrecen University in the Agricultural Laboratory Centre. The elemental analysis with Inductively Coupled Plasma Optical Emission Spectrometer ICP-OES (PerkinElmer Optima 3300 DV ICP-OES) was used for the quantification of all analyzed elements. The ICP-OES instrument has a high precision for multi element content detection. Hungarian standard methods (MSZ and SVM) were used for the determination of the spring oat grain element content, with an analytical deviation allowance of $\pm 10\%$ for repeatability and precision acceptance.

2.7 Data Analysis

GenStat Program 18th version was used for the statistical analysis, where all of the data were subjected to this statistical program. ANOVA analysis with a two factors design was performed for the statistics of the treatments and for average value comparison. Furthermore, the variety and treatment interaction were determined. For the variance analysis, homogeneity and normality tests were performed. In addition, the treatment variety and year interaction factor were performed for the three factors variance analysis. The average values of the spring oat grains for treatment variety and year interaction were compared by using the LSD (least significant difference) with a 5% level of probability. The year analysis was performed separately for each year. The Pearson correlation was performed for the linear correlation. PCA (principal component analysis) with R statistics was used for the treatment differences of the nutrient element content of spring oat grain. The major of the original variance and correlated variables are shown in the orthogonal principal components during the principal components analysis, where a highlighted cluster is shown for the differences of the elemental spring grain content.

3. RESULTS AND DISCUSSION

3.1. Correlation between Normalized Difference Vegetative Index and Leaf Area Index at Different Growth Stages

Table 3 below shows the correlation coefficient between leaf area index (LAI) normalized difference vegetative index (NDVI) measured on different phenological phases (BBCH), giving a dynamic movement of canopy development and leaf area during the vegetative process.

The first strong positive correlation it is observed at LAI results in early phenological stages BBCH13 and BBCH39 ($r = 0.83$) showing a vegetative stability development in the beginning active growing phase. However, a strong negative correlation ($r = -0.91$) it is showed at the LAI late and early phenological stages (BBCH83 and BBCH13) giving a strong suggestion for the phenological changes during the vegetative stage.

Table 3: Pearson correlation coefficient among leaf area index and canopy greenness variation in the experimental year of 2022-2024

	LAI				NDVI					
	BBCH 13	BBCH 39	BBCH 73	BBCH 83	BBCH 13	BBCH 39	BBCH 51	BBCH 73	BBCH 77	BBCH 83
LAI BBCH13	1.00									
LAI BBCH39	0.83	1.00								
LAI BBCH73	-0.75	-0.32	1.00							
LAI BBCH83	-0.91	-0.68	0.81	1.00						
NDVI BBCH13	0.94	0.89	-0.56	-0.77	1.00					
NDVI BBCH39	0.80	0.92	-0.29	-0.57	0.93	1.00				
NDVI BBCH51	0.79	0.90	-0.26	-0.56	0.91	0.97	1.00			
NDVI BBCH73	0.69	0.85	-0.18	-0.44	0.86	0.92	0.95	1.00		
NDVI BBCH77	-0.07	0.21	0.51	0.31	0.20	0.36	0.48	0.61	1.00	
NDVI BBCH83	-0.94	-0.66	0.86	0.94	-0.80	-0.60	-0.57	-0.43	0.37	1.00

Note: green color (positive) correlation, red color (negative) correlation and white color (no) correlation.

Regarding to the NDVI correlation a very strong it is observed between three leaves unfolded and flag leaf stage ($r = 0.93$) and the flag leaf stage with beginning of heading ($r = 0.97$) indicating that the canopy greenness it is consistent during the maximum canopy development process, by reflecting the greenness of the leaf surface in the intensive growth period.

3.2 Photosynthetic Transpiration Dynamics in Response to Foliar Application of Silicon and Sulfur at Different BBCH Growth Stages

The photosynthetic transpiration rate during the moderate drought conditions were significantly different ($p < 0.05$), where the results showed that sulfur foliar treatment had the highest transpiration rate $8.089 \text{ mmol m}^{-2} \text{ s}^{-1}$ at flag leaf stage (BBCH39). Furthermore, during the early milk (BBCH73) phenological stage the foliar treatment showed significant differences ($p < 0.05$) with the highest mean in S and Si+S treatment 16.748 and $16.351 \text{ mmol m}^{-2} \text{ s}^{-1}$ respectively. However a combined treatment of silicon and sulfur showed the lowest transpiration values to overall treatments during the BBCH39 ($5.859 \text{ mmol m}^{-2} \text{ s}^{-1}$) and BBCH73 ($14.829 \text{ mmol m}^{-2} \text{ s}^{-1}$) respectively (Figure 2).

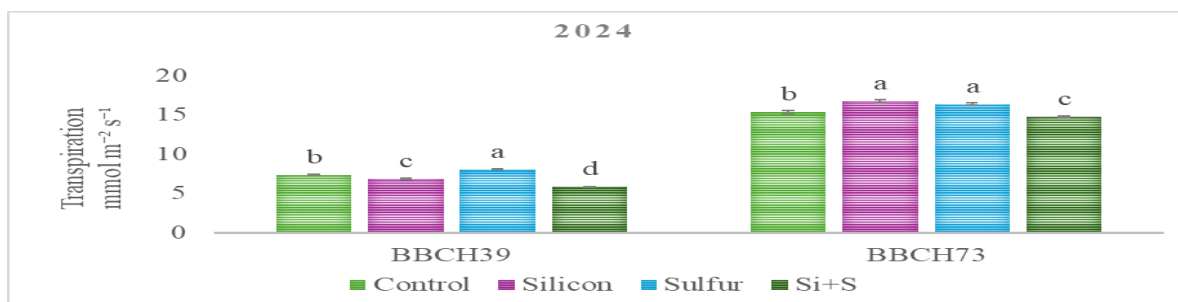


Figure 2: Photosynthetic Transpiration response in spring oat under C, S, Si, Si+S foliar treatments, during flag leaf (BBCH39) and early milk stage (BBCH73) in moderate drought season (Debrecen, 2024).

Note: Clustered columns show annual mean values averages across 8 varieties and 3 replications, with ± 24 standard error of means. Same letter in different treatments means no significant difference within same phenological growing stage, determined by LSD at $p \leq 0.05$ significance level.

Foliar treatment significantly ($p < 0.05$) affected photosynthetic transpiration rate compared to control plots at serious drought conditions in 2022 season for both BBCH51 and BBCH77 growing stages, showing a clear physiological response of the spring oats to the application

of foliar nutrients through the leaves. During the serious drought conditions at the BBCH51 growing stage the highest value were measured with Si+S foliar application ($4.921 \text{ mmol m}^{-2} \text{ s}^{-1}$) and for BBCH77 growing stage the highest value were S foliar treated plots ($3.367 \text{ mmol m}^{-2} \text{ s}^{-1}$). Furthermore, during the serious drought conditions growing seasons the lowest transpiration rate for both each stage (BBCH51 and BBCH77), were founded in control $2.284 \text{ mmol m}^{-2} \text{ s}^{-1}$ and $1.33 \text{ mmol m}^{-2} \text{ s}^{-1}$, respectively. For the mild drought seasons (2023) the foliar application of S and Si+S during the BBCH39 growing stage showed resulted in significantly highest transpiration rate overall treatments with a mean of 9.075 and $8.914 \text{ mmol m}^{-2} \text{ s}^{-1}$, respectively. However, a sole Si treatment resulted in the lowest transpiration values with a mean $5.345 \text{ mmol m}^{-2} \text{ s}^{-1}$, in the BBCH77 phenological stage. Overall, results prove that foliar fertilization during the BBCH51 and BBCH77 phenological stages strongly affected the rate of photosynthetic transpiration of spring oats genotypes, emphasizing the role of foliar applications of S and Si+S for spring oat physiological performance (Figure 3).

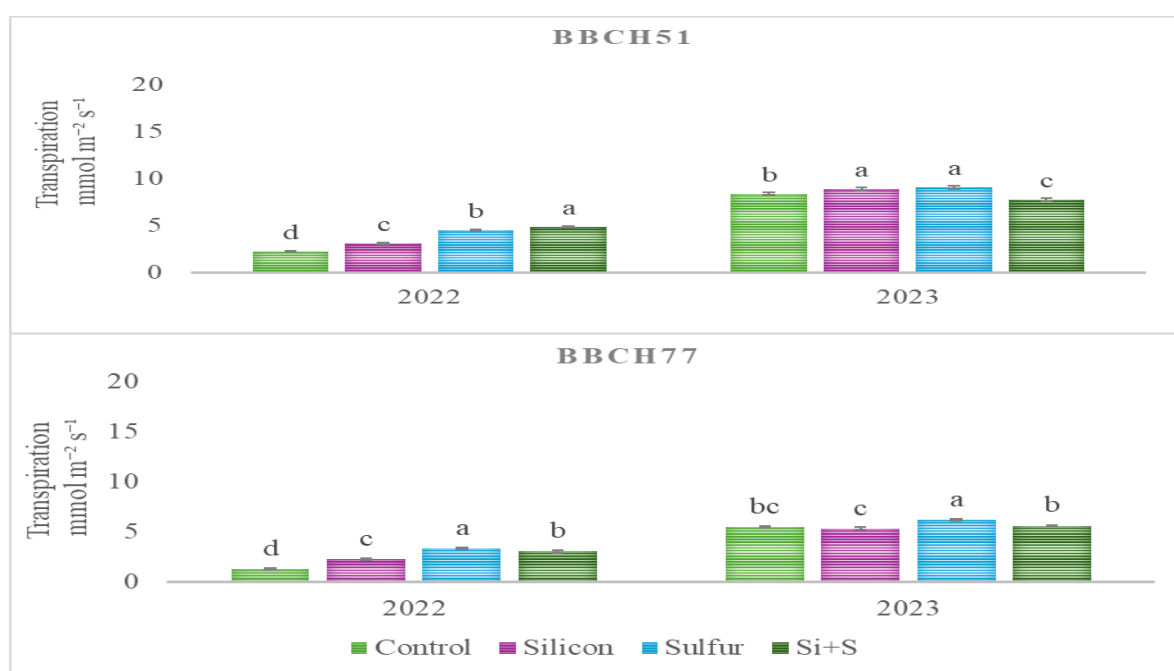


Figure 3: Photosynthetic Transpiration response in spring oat under C, S, Si, Si+S foliar treatments, during beginning of heading (BBCH51) and late milk stage (BBCH77) under serious drought(2022) and mild drought (2023) seasons. (Debrecen, 2022, 2023)

Note: Clustered columns show annual mean values averages across 8 varieties and 3 replications, with ± 24 standard error of means. Same letter in different treatments means no significant difference within same growing seasons, determined by LSD at $p \leq 0.05$ significance level.

3.3 Photosynthetic Total Conductance Dynamics in Response to Foliar Application of Silicon and Sulfur at Different BBCH Growth Stages

Foliar treatment significantly ($p < 0.05$) affected photosynthetic total conductance value compared control plots at the serious drought conditions in 2022 season for both growing stages BBCH51 and BBCH77, showing a highest physiological response of the spring oats to the application of foliar nutrients through the leaves. During the serious drought (2022) conditions at the BBCH51 growing stage the highest value were measured with Si+S foliar application ($0.125 \text{ mol m}^{-2} \text{ s}^{-1}$) and for BBCH77 growing stage the highest value were S foliar treated part ($0.053 \text{ mol m}^{-2} \text{ s}^{-1}$). Furthermore, during the serious drought conditions growing seasons the lowest total conductance rate for both each stage (BBCH51 and BBCH77), were founded in control $0.05 \text{ mol m}^{-2} \text{ s}^{-1}$ and $0.025 \text{ mol m}^{-2} \text{ s}^{-1}$, respectively. For the mild drought seasons (2023) the sole foliar application of Si and S showed the highest photosynthetic total conductance during the BBCH51 and BBCH77 growing phase with a value of $0.248 \text{ mol m}^{-2} \text{ s}^{-1}$ and $0.305 \text{ mol m}^{-2} \text{ s}^{-1}$, respectively. However, the lowest photosynthetic total conductance during the mild drought conditions (2023) were founded with Si+S foliar treatment $0.114 \text{ mol m}^{-2} \text{ s}^{-1}$ at BBCH51 and Control treatment with a mean of $0.241 \text{ mol m}^{-2} \text{ s}^{-1}$ at BBCH77 growing phase (Figure 4).

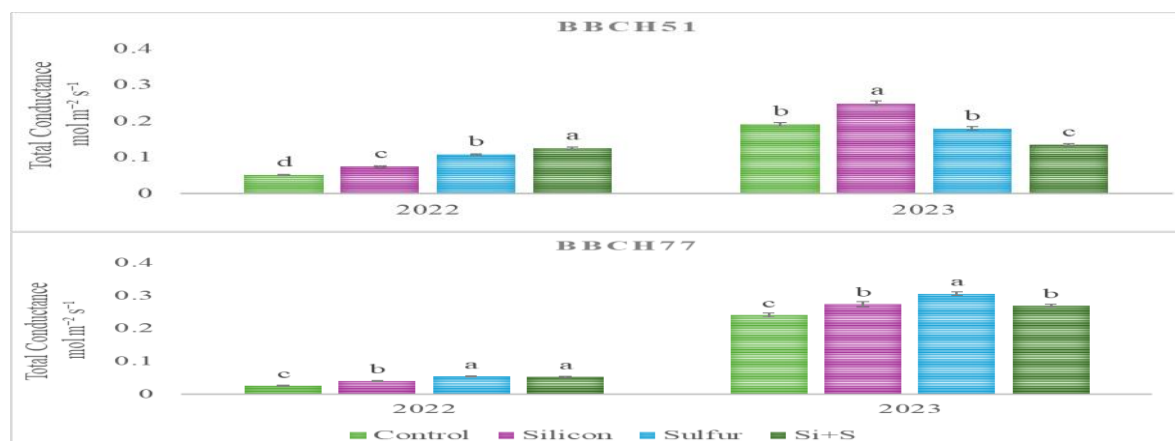


Figure 4: Photosynthetic Total Conductance response in spring oat under C, S, Si, Si+S foliar treatments, during beginning of heading (BBCH51) and late milk stage (BBCH77) under serious drought (2022) and mild drought (2023) seasons. (Debrecen, 2022, 2023)

Note: Clustered columns show annual mean values averages across 8 varieties and 3 replications, with ± 24 standard error of means. Same letter in different treatments means no significant difference within same growing seasons, determined by LSD at $p \leq 0.05$ significance level.

3.4 Effect of Silicon and Sulfur Foliar Treatment and Varietal Divergences on Grain Yield across Spring Oats

Figure 5 show that spring oat grain yield response to Silicon and Sulfur and a combination of them is statistically significant ($p < 0.05$) under same growing season, and strongly dependent on environmental factors during the cultivation period. The overall decrease in grain yield were observed during the serious drought season (2022) as a result of water availability. The foliar treatment with sulfur and a combined silicon and sulfur application gives a relative advantage under serious drought conditions, suggesting a higher yield performance with a mean of 3592 kg ha⁻¹ and 3224 kg ha⁻¹, respectively. The 2023 season it was characterized by mild drought conditions, performance of the grain yield reached the highest record during this season in all treatments compared to other study years. The sulfur foliar application resulted in the highest grain yield production with a mean of 6533 kg ha⁻¹, followed by a combined application of silicon and sulfur 6427 kg ha⁻¹, while the silicon and control foliar application showed the lowest values 5924 and 6322 kg ha⁻¹, respectively.

The 2024 production seasons is characterized by moderate drought conditions, showing a intermediate seasons between extreme drought stress (2022) and mild drought conditions (2023) giving a better overview on yield stability based on the intensity of drought stress. Grain yields in this production season were significantly ($p < 0.05$) compared to 2022 and to 2023 production season, reflecting an environmental conditions importance on yield stability. Sole sulfur application and a combination of it with silicon resulted in higher grain yields (5628 kg ha⁻¹ and 5499 kg ha⁻¹), which showed a statistically significant difference ($p < 0.05$) with control and sole silicon foliar treatment, confirming that under moderate stress conditions (2024) the foliar treatment with applying nutrient elements is an important factor for grain yield productivity.

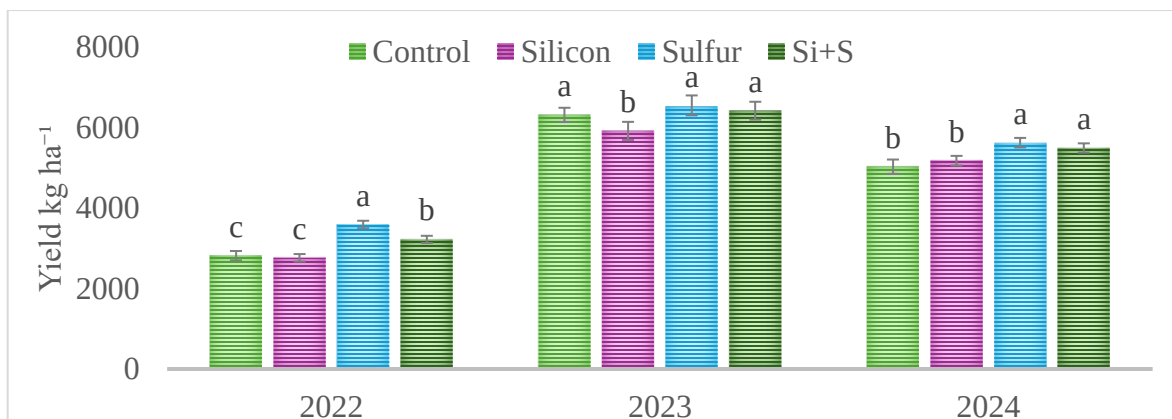


Figure 5: Grain Yield response in spring oat under C, S, Si, Si+S foliar treatments (Debrecen, 2022-2024).

Note: Clustered columns show average values across 8 varieties and 3 replications, with ± 24 standard error of means. Same letter in different treatments means no significant difference within same growing seasons, determined by LSD at $p \leq 0.05$ significance level.

Experimental data for eight spring oat genotypes over the three production seasons (2022-2024) show the statistically significant ($p < 0.05$) factor of environmental conditions and varietal divergences in response to grain yield productivity. In the serious drought conditions year (2022) yield were significantly ($p < 0.05$) lower in all varieties compared to other production years and within the same period, reflecting a lower grain filling capacity during the serious drought conditions. However, during these serious environmental drought conditions there were significant differences ($p < 0.05$) between the studied genotypes with a mean ranging from 2295 kg ha⁻¹ in GK Kormoran to 3549 2295 kg ha⁻¹ Panni genotype. In the mild drought season (2023) the highest yield was recorded in all varieties compared to the serious drought (2022) and moderate drought (2024) seasons, expressing spring oat genetic potential under mild drought conditions. Grain yield ranges from (4330 kg ha⁻¹) GK Kormorán to (8003 kg ha⁻¹) for Mv Ménes, resulting in a significant varietal differentiation. 2024 was characterized by moderate drought conditions, the highest yield is recorded in all varieties compared to serious drought environmental production year (2022), which indicates a great genetic potential expression. Grain yields ranges from lowest variety GK Kormoran (4240 kg ha⁻¹) to the highest production variety Mv Menes (6031 kg ha⁻¹) (Figure 6).

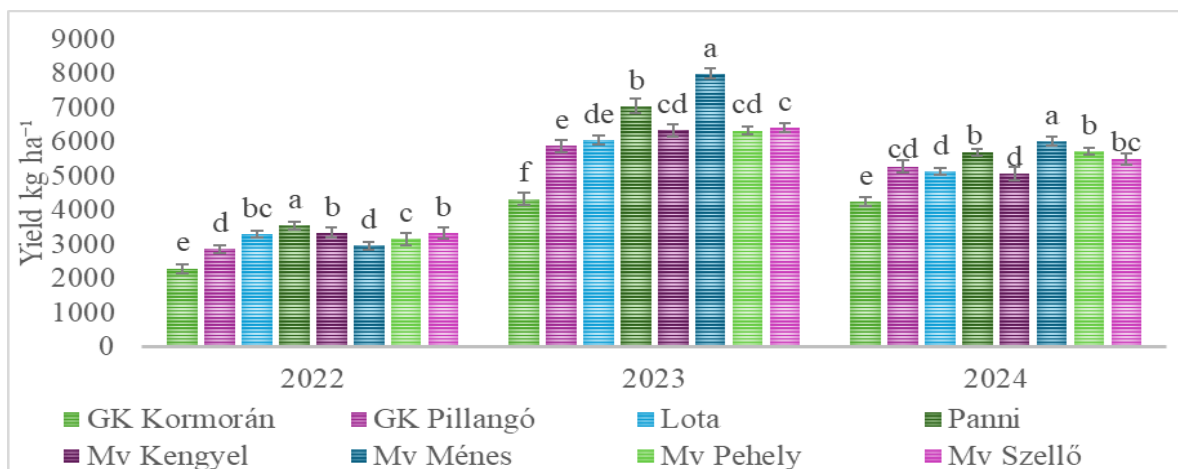


Figure 6: Grain Yield response of spring oat varieties, during three cultivation years (Debrecen, 2022-2024).

Note: Clustered columns show average values across 4 treatments and 3 replications, with ± 12 standard error of means. Same letter in different variety means no significant difference within same growing seasons, determined by LSD at $p \leq 0.05$ significance level.

3.5 Effect of Silicon and Sulfur Foliar Treatments on the Macroelement Content of Spring Oat Genotypes

Foliar treatments resulted in distinct macroelement response patterns depending on water availability. In seasons with relatively adequate water availability (2023 and 2024), foliar sulfur application significantly increased the concentrations of all analyzed macroelements. Under serious drought stress (2022), however, the combined Si + S treatment resulted in the highest accumulation of K, P, S, Mg and Ca, while Si alone had no consistent positive effect.

Across all three years, sulfur application consistently produced the most favorable effect on potassium accumulation, irrespective of water availability, while the combined Si+S treatment demonstrated a similarly beneficial impact. In addition, sulfur-containing treatments consistently enhanced grain P content irrespective of seasonal conditions. S concentrations were significantly higher under the Si+S foliar application in 2022 season, whereas sole S foliar application resulted in increased S accumulation for 2023 and 2024 seasons. Across all seasons, control plots consistently showed the lowest Mg and Ca contents (Figure 7).

3.6 Effect of Silicon and Sulfur Foliar Treatments on the Microelement Content of Spring Oat Genotypes

Analysis of the data indicates that different seasons and foliar treatments caused statistically significant differences in the accumulation of the microelements sodium (Na), silicon (Si), iron (Fe), manganese (Mn), and copper (Cu). Under severe drought conditions (2022), the combined Si+S treatment produced the highest accumulation of all analyzed micronutrients. In contrast, under more favorable moisture conditions (2023-2024), sulfur application was most effective in increasing Na, Fe, Mn and Cu concentrations, while Si alone consistently increased only Si content (Figure 8).

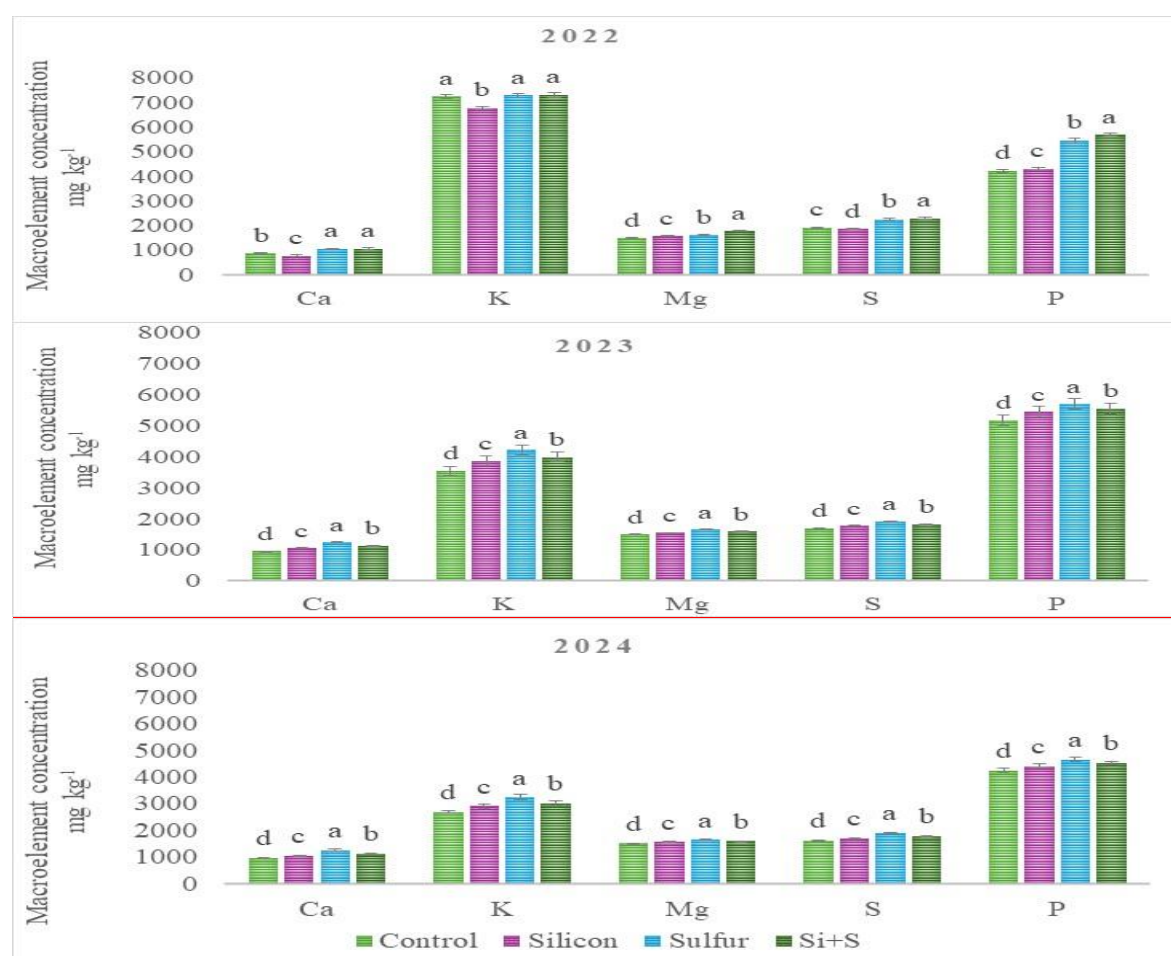


Figure 7: The macroelement concentration in spring oats whole grains under sole and combined silicon and sulfur application (Debrecen, 2022-2024).

Note: Average values are presented in columns for eight varieties and three repetitions ($n = 24$), $\pm$ standard error. Concentration in the same macroelement and same cultivation seasons presented with different letters shows significant differences for foliar application (LSD statistics at $p \leq 0.05$).

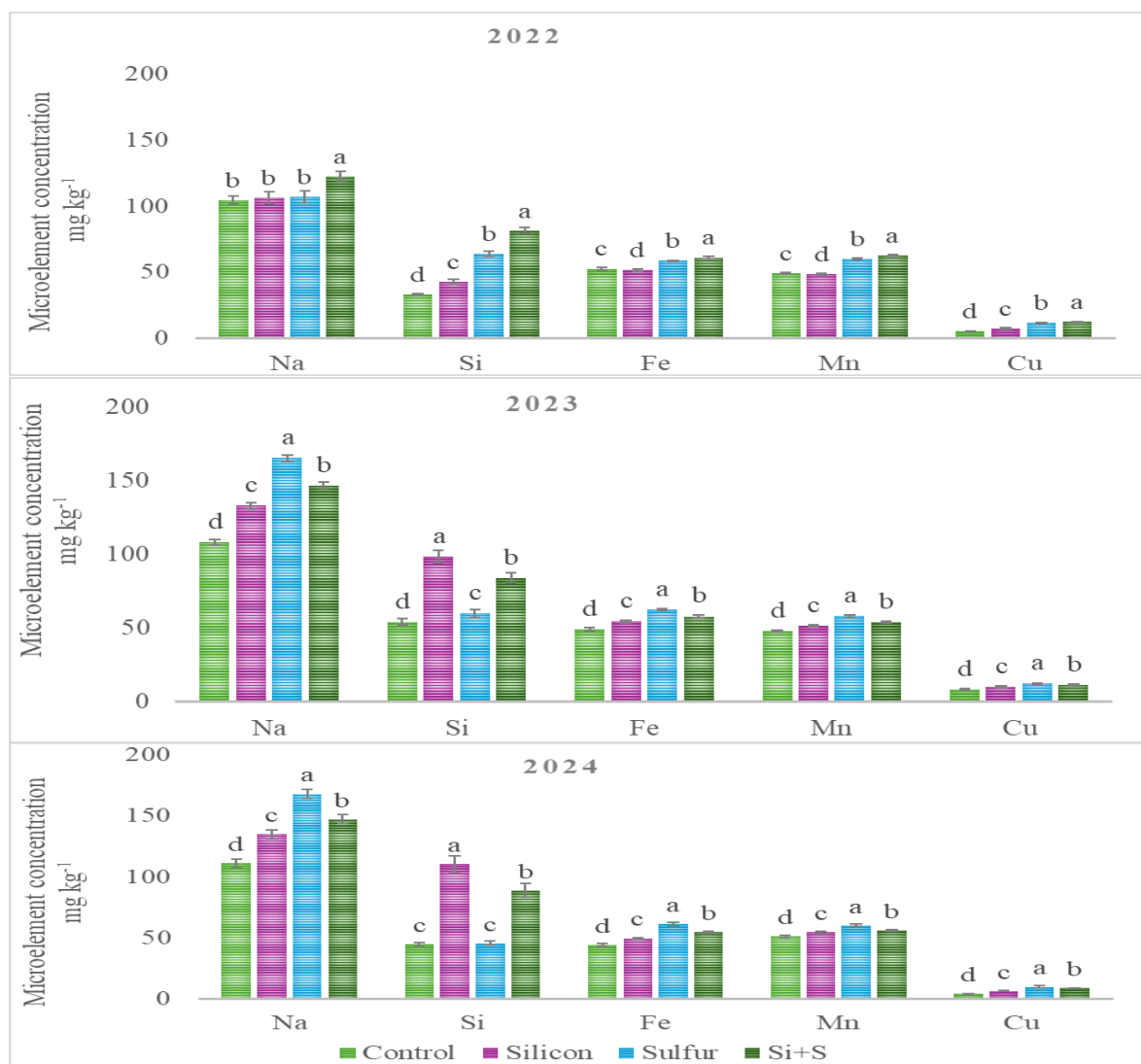


Figure 8: The microelement concentration in spring oats whole grains under sole and combined silicon and sulfur application (Debrecen, 2022-2024).

Note: Average values are presented in columns for eight varieties and three repetitions ($n = 24$), $\pm$ standard error. Concentration in the same microelement and same cultivation seasons presented with different letters shows significant differences for foliar application (LSD statistics at $p \leq 0.05$).

3.7 Principal Component Analysis results of silicon and sulfur treatments on macro- and microelement contents of spring oat grains

The results of PCA performed on the combined dataset for 2022–2024 are shown in Figure 9. The results show a stable, year-independent, multi-component pattern in relation to foliage treatments. The first principal component (Dim1), which explains 40.4% of the total variance, is primarily determined by Fe, Cu, Mg, and S (load 0.77–0.85), but Ca also contributes significantly. These elements therefore represent the dominant axis along which

the effect of the treatment was consistently manifested in all three years. Na and Si show a moderately negative or nearly neutral correlation with PC1, indicating a weaker or more variable response. The second principal component (Dim2), which accounts for 20.7% of the variation, is strongly influenced by K and S (with loadings of 0.901 and 0.619, respectively), suggesting that potassium dynamics—and to a lesser extent sulfur—were responsible for the secondary differentiation between treatments. Other nutrients, including Fe, Mg, and P, contribute only marginally to Dim2, reflecting their more stability over time. Overall, the two principal components together explain 61.1% of the total variability, indicating that the effect of treatments on the composition of oat grains follows robust, multi-year trends (Figure 9).

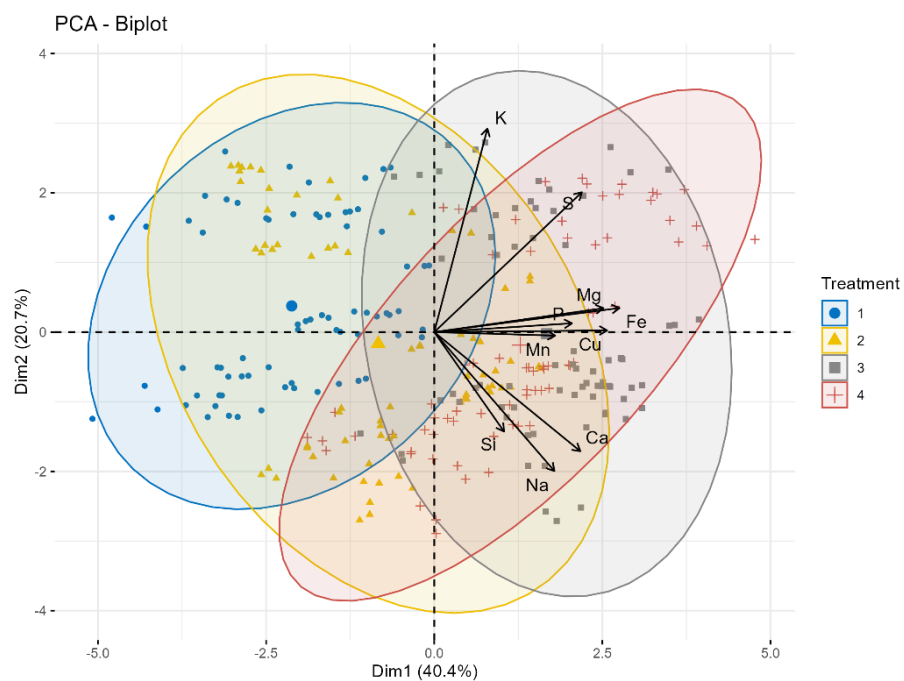


Figure 9: The illustrating of PCA - principal component analysis biplot for the relationship of treatments on macro/micro element concentration under series, moderate and mild drought conditions (2022-2024). Dim1= 40.4 %, Dim2 = 20.7 %, making a total variability of 61.1 %. Treatments. 1=control, 2=Silicon, 3=Sulfur, 4=Si+S foliar treatments.

4. NEW SCIENTIFIC RESULTS

1. Severe drought (PaDI=11.6 °C 100 mm⁻¹) substantially altered the temporal dynamics of spring oat canopy development, causing an earlier peak (BBCH73) and accelerated decline (BBCH83) of LAI and NDVI compared to mild and moderate drought (PaDI=4.3-6.5 °C 100 mm⁻¹; BBCH73) conditions.
2. Combined foliar applications of silicon and sulfur in spring oats resulted in significantly lower LAI (Si+S: 3.26 m² m⁻²; control: 3.91 m² m⁻²) and NDVI (Si+S: 0.46; control: 0.52) values at the BBCH 83 phenological stage during severely drought-affected growing season. Under more favorable water supply conditions, the effects of the treatments were not statistically significant.
3. Under severe drought conditions, Si, S and Si+S treatments significantly enhanced the photosynthetic performance of spring oat. The effects of foliar-applied silicon and sulfur on the assimilation rate, transpiration and stomatal conductance were strongly dependent on the developmental stage. The combined Si+S treatment was most effective at the early reproductive stage (BBCH51), whereas sulfur alone provided the greatest benefits during grain filling (BBCH77). Sole Si application also improved photosynthetic parameters relative to the control, although its effect was significantly weaker than those of the S and Si+S treatments.
4. Si and S treatments did not affect thousand grain weight in any of the growing seasons. Genetic differences among the cultivars were observed in all three years; however, statistically significant differences were detected only under the severe drought conditions of 2022. The thousand grain weight of the cultivars Lota (28.9 g) and Mv Pehely (27.4 g) was significantly higher than that of the other cultivars evaluated (23.1-25.3 g).
5. Sulfur foliar fertilization consistently improved spring oat grain yield under varying drought intensities, with the strongest response (+22.9%) observed under severe drought conditions, and the lowest (+3.2%) under mild drought, whereas silicon applied alone showed limited effectiveness.

6. Under relatively favorable water supply conditions, foliar sulfur application significantly increased the concentration of all measured elements, with the strongest response observed for Cu (+47.4% compared with the control) and the weakest for Mg (+8.5%). Silicon application alone had limited or even negative effects, particularly under severe drought conditions, where it reduced K (-6.4%), S (-2.4%), and Ca (-13%) concentrations despite increasing Si accumulation in the grain. Under drought stress, the combined Si+S treatment significantly enhanced both macro- and micronutrient concentrations in the grain, with the strongest effects observed for Mg (+9.57%) and Si (+43.2%) relative to the control.
7. The cultivar Mv Pehely exhibited the highest overall grain nutrient accumulation across the growing seasons (2022–2024), particularly for sulfur (S) and magnesium (Mg). In contrast, the genotype GK Kormorán exhibited the highest and most consistent iron (Fe) accumulation across all seasons. The cultivars GK Pillangó and Mv Szellő consistently showed lower grain nutrient concentrations.

5. PRACTICAL UTILIZATION OF RESULTS

1. In spring oat, sulfur and combined silicon + sulfur applications during the growing season (three leaves unfolded-BBCH13, flag leaf stage-BBCH39, early milk stage-BBCH73) exert positive effects on both yield quantity and quality.
2. The sulfur foliar treatment can increase the yield from 3.2% up to 22.9% depending on the environmental conditions.
3. Selecting the best genotypes for the yield performance is an important application for the climate adaptive spring oat management production. On chernozem soil in the Hajdúság region, averaged across the experimental years, the cultivars Mv Ménes, Mv Szellő, Lota, and Panna achieved yield levels exceeding the overall varietal mean.
4. The cultivar Panna recorded the highest yield under severe drought conditions (2022), exceeding that of the lowest-performing cultivar, GK Kormorán, by 54.6%. Mv Ménes showed the best performance during mild (2023) and moderate (2024) drought seasons, with yields 45.9% and 29.6% higher than GK Kormorán.
5. The sole sulfur application can be used in the increase of nutritional value of spring oat, specifically for the increase of potassium, phosphorus, sulfur, calcium, sodium, iron, manganese, and copper grain content, while silicon and sulfur combined application, it can be used for the increase of magnesium and silicon grain content.
6. In the production of high-quality spring oat, the selection of an appropriate genotype is of decisive importance. Based on our investigations, the cultivars Mv Pehely and GK Kormorán exhibited superior grain quality, whereas GK Pillangó and Mv Szellő showed lower macro- and micronutrient contents during the studied period (2022–2024).

7. BIBLIOGRAPHY

1. *Aula, L. - Dhillon, J. S. - Omara, P. - Wehmeyer, G. B. - Freeman, K. W. - Raun, W. R.:* (2019), World Sulfur Use Efficiency for Cereal Crops. *Agron. J.*, 111: 2485-2492. <https://doi.org/10.2134/agronj2019.02.0095>
2. *BARNABÁS, B. - JÄGER, K. - FEHÉR, A.:* (2008), The effect of drought and heat stress on reproductive processes in cereals. *Plant, Cell & Environment*, 31: 11-38. <https://doi.org/10.1111/j.1365-3040.2007.01727.x>
3. *Forsberg, R. A. – Dale, L. R.:* 1995. “Agronomy of Oats.” In *The Oat Crop*, edited by Robert W. Welch, 223–51. Dordrecht: Springer Netherlands. https://doi.org/10.1007/978-94-011-0015-1_8.
4. *Fróna, D. – János, S. – Mónika, H. R.:* 2019. “The Challenge of Feeding the World.” *Sustainability* 11 (20): 5816. <https://doi.org/10.3390/su11205816>.
5. *Loskutov, I. G. - Gnutikov, A. A. - Blinova, E. V. – Rodionov, A. V.:* 2021. “The Origin and Resource Potential of Wild and Cultivated Species of the Genus of Oats (*Avena* L.).” *Russian Journal of Genetics* 57 (6): 642–61. <https://doi.org/10.1134/S1022795421060065>.
6. *Mills, R. T. E. - Gavazov, K. S. - Spiegelberger, T. - Johnson, D – Buttler, A.:* 2014. “Diminished Soil Functions Occur under Simulated Climate Change in a Sup-Alpine Pasture, but Heterotrophic Temperature Sensitivity Indicates Microbial Resilience.” *Science of The Total Environment* 473–474 (March):465–72. <https://doi.org/10.1016/j.scitotenv.2013.12.071>.
7. *Narayan, O. P. - Kumar, P. - Yadav, B. - Dua, M. – Johri, A. K.:* 2023. “Sulfur Nutrition and Its Role in Plant Growth and Development.” *Plant Signaling & Behavior* 18 (1): 2030082. <https://doi.org/10.1080/15592324.2022.2030082>.
8. *Porter, J. R. – Gawith, M.:* 1999. “Temperatures and the Growth and Development of Wheat: A Review.” *European Journal of Agronomy* 10 (1): 23–36. [https://doi.org/10.1016/S1161-0301\(98\)00047-1](https://doi.org/10.1016/S1161-0301(98)00047-1).

9. *Gelybó, G. - Tóth, E. - Farkas, C. - Horel, Á. - Kása, I – Bakacsi, Z.*: 2018. “Potential Impacts of Climate Change on Soil Properties.” *Agrokémia És Talajtan* 67 (1): 121–41.
<https://doi.org/10.1556/0088.2018.67.1.9>.
10. *Zhang, X. - Liu, Y. - Zhang, Z. - Liang, Q. – Wang, G.*: 2024. “Soil Moisture Influences Wheat Yield by Affecting Root Growth and the Composition of Microbial Communities under Drip Fertigation.” *Agricultural Water Management* 305 (December):109102.
<https://doi.org/10.1016/j.agwat.2024.109102>.



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Candidate: Bekir Bytyqi
Doctoral School: Kálmán Kerpely Doctoral School
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List of publications related to the dissertation

Hungarian book chapters (2)

1. Forgács, F., Virág, I. C., **Bytyqi, B.**, Gaganetz, D., Kutasy, E.: Őszi és tavaszi zab genotípusok minőségvizsgálati eredményei.
In: Paradigmaváltás a növénytermesztésben : A magyar növénytermesztők válasza a nemzetközi trendekre. XXXI. Növénytermesztési Tudományos Napok - Összefoglalók. Szerk.: Bóna Lajos, Kovács Szilvia, Molnár István, Pauk János, Polgár Zsolt, Veres Szilvia, Vida Gyula, Debreceni Egyetem, Debrecen, 75-79, 2025. ISBN: 9789634907190
2. Kutasy, E., Virág, I. C., **Bytyqi, B.**, Csajbók, J., Forgács, F.: Martonvásári őszi és tavaszi zab genotípusok produktivitása eltérő évjáratokban.
In: Hagyomány és megújulás: A magyar növénytermesztés helyzete a változó világban, XXX. Növénytermesztési Tudományos Napok, Összefoglalók. Szerk.: Bóna Lajos, Molnár István, Pauk János, Polgár Zsolt, Veisz Ottó, Vida Gyula, HUN-REN Agrártudományi Kutatóközpont, Martonvásár, 52-56, 2024. ISBN: 9789638351500

Foreign language international book chapters (1)

3. Kutasy, E., Csajbók, J., Virág, I. C., Forgács, F., **Bytyqi, B.**: Response of spring oat varieties to silicon and sulphur fertilization in heavy drought.
In: Agriculture for better tomorrow. Innovation and entrepreneurship. 60th CROATIAN AND 20th INTERNATIONAL SYMPOSIUM ON AGRICULTURE Proceedings. Eds.: Ivana Majić, Zvonko Antunović, Faculty of Agrobiotechnical Sciences Osijek University Josip Juraj Strossmayer in Osijek, Osijek, Croatia, 89-93, 2025. ISBN: 24595543

Foreign language scientific articles in Hungarian journals (1)

4. **Bytyqi, B.**, Kutasy, E.: Leaf reflectance characteristics and yield of spring oat varieties as influenced by varietal divergences and nutritional supply.
Agrártud. közl. 2023 (1), 29-34, 2023. ISSN: 1587-1282.
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Foreign language scientific articles in international journals (2)

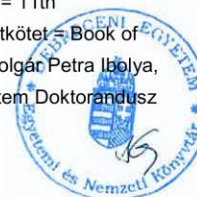
5. **Bytyqi, B.**, Forgács, F., Melash, A. A., Virág, I. C., Csajbók, J., Appiah, E. A., Kutasy, E.: Foliar application of silicon and sulfur modifies grain mineral composition of spring oats (*Avena sativa* L.) under contrasting seasonal drought conditions.
Plants-Basel. 15 (2), 1-28, 2026. ISSN: 2223-7747.
DOI: <http://dx.doi.org/10.3390/plants15020316>
IF: 4.7 (2025)
6. Kutasy, E., Diósi, G., Bódi, E., Nagy, P. T., Melash, A. A., Forgács, F., Virág, I. C., Vad, A., **Bytyqi, B.**, Buday, T., Csajbók, J.: Changes in plant and grain quality of winter oat (*Avena sativa* L.) varieties in response to silicon and sulphur foliar fertilisation under abiotic stress conditions.
Plants-Basel. 12 (4), 1-18, 2023. EISSN: 2223-7747.
DOI: <http://dx.doi.org/10.3390/plants12040969>
IF: 4

Foreign language conference proceedings (2)

7. Kutasy, E., Csajbók, J., Virág, I. C., **Bytyqi, B.**, Forgács, F.: Ecotype x foliar nutrition interactions in oats: implications for climate resilience.
In: Smart and Resilient Agriculture - Safety for Future Generations: 61st Croatian and 21st International Symposium on Agriculture: Proceedings. Ed.: Željka Klir Šalavardić, Marin Kovačić, Faculty of Agrobiotechnical Sciences Osijek, University Josip Juraj Strossmayer in Osijek, Bol, Croatia, 58-62, 2026.
8. **Bytyqi, B.**, Kutasy, E.: Physiormorphology responses of spring oat varieties in Silicon and Sulphur application to alleviate drought stress.
In: XI. Interdiszciplináris Doktorandusz Konferencia 2022 = 11th Interdisciplinary Doctoral Conference 2022 : Tanulmánykötet = Conference Book. Szerk.: Kajos Luca Fanni, Bali Cintia, Puskás Tamás, Szabó Rebeka, Pécsi Tudományegyetem Doktorandusz Önkormányzat, Pécs, 80-87, 2023. ISBN: 9789636260705

Foreign language abstracts (1)

9. **Bytyqi, B.**: Physiormorphology responses of spring oat varieties in Silicon and Sulphur application to alleviate drought stress.
In: XI. Interdiszciplináris Doktorandusz Konferencia 2022. november 25-26 = 11th Interdisciplinary Doctoral Conference 25-26th of November 2022 : absztraktokötet = Book of Abstracts. Szerk.: Kajos Luca Fanni, Bali Cintia, Puskás Tamás, Horváth-Polgár Petra Ibolya, Glázer-Kniesz Adrienn, Tislér Ádám, Kovács Eszter, Pécsi Tudományegyetem Doktorandusz Önkormányzat, Pécs, 18, 2022. ISBN: 9789636260699





List of other publications

Foreign language scientific articles in Hungarian journals (1)

10. Melash, A. A., Vad, A., **Bytyqi, B.**, Ábrahám, É. B.: Harnessing diversity in durum wheat (*Triticum turgidum* L.) to enhance climate resilience and micronutrient concentration through genetic and agronomic biofortification.
Agrártud. közl. 2022 (2), 9-20, 2022. ISSN: 1587-1282.
DOI: <http://dx.doi.org/DOI: 10.34101/ACTAAGRAR/2/11053>

Foreign language scientific articles in international journals (2)

11. Melash, A. A., **Bytyqi, B.**, Nyandi, M. S., Vad, A., Ábrahám, É. B.: Chlorophyll Meter: A precision agricultural decision-making tool for nutrient supply in durum wheat (*Triticum turgidum* L.) cultivation under drought conditions.
Life (Basel). 13 (3), 1-20, 2023. EISSN: 2075-1729.
DOI: <http://dx.doi.org/10.3390/life13030824>
IF: 3.2
12. Melash, A. A., Bogale, A. A., **Bytyqi, B.**, Nyandi, M. S., Ábrahám, É. B.: Nutrient management:bas a panacea to improve the caryopsis quality and yield potential of durum wheat (*Triticum turgidum* L.) under the changing climatic conditions.
Front. Plant Sci. 14, 1-22, 2023. EISSN: 1664-462X.
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Total IF of journals (all publications): 16

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