HUNGARIAN UNIVERSITY OF AGRICULTURE AND LIFE SCIENCES

The Impact of Drought and Temperature Stress on Wheat and Maize Production

Thesis of the PhD Dissertation

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1 INTRODUCTION

Plants are subject to a range of environmental stresses, encompassing abiotic stresses, which refer to non-biological factors that can have detrimental effects on plant growth and development. Wheat (*Triticum aestivum* L.) and maize (*Zea mays* L.) are the most essential and cultivated field crops worldwide. Abiotic stresses, including but not limited to drought, extreme temperatures, flooding, and exposure to chemicals, have been observed to result in substantial declines in crop productivity, quality, and yield. These adverse effects have been found to have significant economic implications for the agricultural sector, leading to financial losses. In the year 2022, the agricultural sector in Hungary experienced a significant decline in production due to the substantial effects of drought. Similarly, the United States encountered a substantial impact on approximately 85% of its cropland, leading to agricultural losses amounting to 22.2 billion US dollars according to the United States Department of Agriculture.

These environmental restrictions do not seem to be diminishing. Increased temperatures and decreasing precipitation are predicted by global climate change, which is likely to intensify the negative consequences of water shortage on agriculture. Less rainfall will increase the extent of irrigated land, leading to soil salinization.

Abiotic stresses can induce various physiological, biochemical, and molecular responses in plants, including changes in gene expression, protein synthesis, osmolyte accumulation, and reactive oxygen species (ROS) scavenging. These responses minimize stress-induced damage and promote plant survival under harsh circumstances. Nevertheless, chronic exposure to stress may cause irreparable tissue damage, decreasing plant development and yield.

Germination is a physiological process that initiates and develops a seedling by triggering a cascade of biological and biochemical reactions. Germination affects both the ultimate production and quality of a crop. Successful production requires the growth of sturdy, well-developed seedlings, and one of the main goals of seedling production is to produce a viable plant from any single seed. Temperature and water availability significantly affect the biological and biochemical enzymatic activities in germination and seedling growth stages.

Seed priming is a technique that involves soaking seeds in a solution to initiate the germination process before planting. The strategy aims to improve seedling emergence, plant growth, and tolerance to various environmental stresses, including abiotic stresses such as drought, flood, and extreme temperatures. Seeds exposed to abiotic stresses during their development often become dormant and have reduced germination rates. Seed priming can help overcome these challenges by triggering the metabolic processes required for germination before planting. This method enhances the seed's ability to germinate and grow under unfavorable environmental conditions. Seed priming can be an effective method for enhancing plant growth and improving yield under stress conditions. This technique is gaining popularity in agriculture as a sustainable and cost-effective approach to enhancing crop productivity and reducing the negative impact of abiotic stresses on plant growth.

In recent years, significant advances have been made in understanding the mechanisms underlying plant responses to abiotic stresses. Molecular and genomic studies have identified genes and pathways involved in stress sensing, signal transduction, and stress adaptation. Furthermore, physiological and morphological studies have been ongoing to cope with the increased impact of these stresses.

Additionally, plant-microbe interactions have been shown to be important in improving plant tolerance to abiotic stresses.

This dissertation aims to review the current understanding of plant responses to abiotic stresses, focusing on drought and heat stress and novelizing new strategies to face these conditions. This study also focuses on the seed priming technique to enhance germination and plant tolerance in the later stages of wheat and maize life. The study also investigates the role of plant-microbe interactions in improving plant tolerance to abiotic stresses. Drought and temperature stress signaling is an important area concerning increased plant productivity. However, our knowledge of the techniques underlying the responses of plants to such environmental stresses is still somewhat limited.

The findings of this study contribute to a better understanding of plant responses to abiotic stresses and aid in developing novel strategies for improving plant tolerance to adverse environmental conditions. Thus, it is essential to investigate the plant mechanisms of stress tolerance in order to identify novel management components and techniques for enhancing crop resistance and tolerance.

1.1 The Study Importance

Drought, heat, and waterlogging are the three major abiotic factors that may reversely impact the establishment, growth, development, and yield of wheat and maize crops. These crops are primary food sources and are extensively farmed around the globe, improving their resistance to these pressures essential for global food security. However, these abiotic factors can diminish plant growth, agricultural output, and crop failure, affecting food security and farmer income.

Overall, it is impossible to overlook the significance of these abiotic factors on wheat and maize crops. Therefore, it is crucial to develop strategies and technologies to mitigate their effects on crop productivity and quality. Novel agriculture practices can be used to develop management techniques of drought-, waterlogging-, and heat-tolerant, along with agronomic practices, including crop rotation, soil management, and irrigation can also lessen the effect of these pressures on agricultural output.

1.2 The Study Problem

Significant obstacles to the development and productivity of wheat and maize are posed by abiotic factors such as drought, heat, and waterlogging. This research topic aims to comprehend how these environmental stressors impact plants' growth, development, and productivity. Furthermore, as the frequency of severe weather events increases due to global warming, it is crucial to examine the effect of these stresses on plants and their capacity to withstand them.

A water shortage in the soil causes drought stress, which may restrict plant development and reduce agricultural production. Heat stress may wreak havoc on plant tissues and cells, resulting in stunted development and decreased yield. Waterlogging stress occurs when the soil gets saturated with water, restricting the availability of oxygen to plant roots and resulting in decreased growth and yield. These abiotic stressors may lead to decreased crop yields, diminished crop quality, and even crop failure, resulting in economic losses for farmers and threatening global food security. Therefore, developing strategies to mitigate the impact of these abiotic stresses on crop productivity and quality, such as developing drought-, heat-, and waterlogging-tolerant crop varieties and implementing suitable agronomic practices, is essential for ensuring sustainable agriculture and global food security.

2 OBJECTIVES TO ACHIEVE

This study directed to investigate the following objectives:

1. Determining the effect of abiotic stress on wheat and maize seed germination under controlled laboratory conditions, and optimizing the germination, seedlings growth, and antifungal application techniques. A novel technique can be written down and instructed?
2. Investigating the effect of the seed priming technique on enhancing seed germination and plant tolerance in the later stages of wheat life. Could this technique induce tolerance or stimulate certain defense plant mechanisms to different abiotic stresses?
3. Evaluating the effects of abiotic stress on the morphological parameters of plant growth and development, including tillers number, leaf area, and plant height. What are the affected traits and what are the best treatments used?
4. In field trials, determining the influence of abiotic stress on yield and yield components, including grain yield, number of ears per plant, and number of grains per ear in wheat and maize. Can determine the effect of abiotic stress on the yield quantity and quality?
5. Examine wheat and maize's physiological and biochemical responses to abiotic stress, including photosynthesis activity and chlorophyll concentration alterations. Is there a certain agricultural technique may help enhance plant production and environmental resilience by understanding plant response to abiotic stress?
6. Evaluate in-crop nitrogen uptake, assimilation, and mobilization in plants under abiotic stress. Do nitrogen fertilizer application rates, splitting, and timings have an effect on improving nitrogen use efficiency (NUE) and mitigating the reverse effect of abiotic stress on crop productivity? What about the microorganism’s application on mitigating the impact of abiotic stresses?
7. Evaluate the effect of irrigation in different growth stages on yield components, quality, and quantity. Is there any effect of timing and frequency of irrigation throughout growth stages may significantly affect yield components, quality, and quantity?

The primary objective of this study is to provide a comprehensive analysis of the impact of abiotic stress on the growth and development of wheat and maize, while also exploring strategies to improve the resilience of these crops under stressful environmental conditions. Ensuring food security in the context of climate change necessitates the implementation of various management strategies. These strategies encompass optimizing seed germination and emergence, employing seed priming techniques, harnessing the potential of microorganisms, adopting diverse nitrogen application and splitting methods, and implementing varied irrigation regimes.

3 MATERIALS AND METHODS

The research methodology employed in this study pertains to the systematic approach and techniques utilized to design, conduct, and analyze a research investigation. The provided statement delineates the sequential actions, methodologies, and instruments employed in collecting and examining data to address research inquiries or validate hypotheses. An appropriately structured research methodology guarantees the study's dependability, validity, and credibility, thereby ensuring the reliability and generalizability of the findings to a broader population. The laboratory and field experiments were conducted in the experimental labs and fields belonging to the Agronomy Institute – Hungarian University of Agriculture and Life Sciences, located at 2100 Gödöllő, Pest, Hungary (coordinates: 47.594315, 19.368984).

3.1 Plant Materials

I. Margitta, maize hybrid: The most significant benefit of the Margitta hybrid is the swift water loss. The FAO number falls in the middle of the 300 group; this means a higher potential yield, but due to the fast water loss, it ripens earlier than others in the same group. Margitta has a robust appearance and ripening on a green stem. Typically, the cobs bend down while ripening. Due to its remarkable stress tolerance, this hybrid’s optimal sowing and harvesting range is wide. This dentiform maize hybrid plants at a density of 65–70,000 plant/ha, the number of seed rows on a cob is 16–18 with a seed-cob ratio of 86.8%, and the cob length is 21–22 cm.

II. Alföld 90, wheat variety: The seeds of a regionally commonly grown variety of Hungarian wheat named Alföld 90 were obtained from a grower and used. It is a high winter tolerance wheat variety with a 75–95 cm plant height and awed spikes. Alföld 90 is sensitive to powdery mildew disease and has a total tolerance to stem rust disease. It is an early Hungarian variety and is cultivated in dry regions.

III. Mv Felleg, wheat variety: A new, high-yielding early milling wheat variety that approaches the premium baking category in quality. Its excellent technological quality is due to its ancestor, the popular Mv Kolo variety, but it is far superior to its predecessor in yield. It is productivity of 8.5-9.5 t/ha. Its typical quality characterizations are: hard kernal type, TKW is 40-45 g, crude protein content is 13-15%, wet gluten content is 25-35%, and farinograph group A1-A2. In addition, it has a total resistance level to stem rust, with excellent resistance to fusarium head blight, leave-plight, leave rust, yellow rust, and powdery mildew. The recommended fertilizer dose is 140-170 kg of nitrogen as an active ingredient per hectare.

IV. Mv Ménrót, wheat variety: An early, high-yielding variety with excellent yield stability. A top variety when intensive technology is applied. Depending on cultivation intensity, baking quality may vary between B1 and A2 per harvest year. It has a complex and good disease resistance. It is productivity of 9.00-10.0 t/ha. Its typical quality characterizations are: large steely kernels type, TKW is 45-50 g, crude protein content is 12-14%, wet gluten content is 29-32%, and farinograph group is A2. In addition, it has a total resistance level to stem rust, with good resistance to fusarium head plight, leave-plight, leave rust, yellow rust, and powdery mildew. The recommended fertilizer dose is 150-180 kg of nitrogen ingredient per hectare.

V. Mv Nemere, wheat variety: A high-yielding, mid-season maturing milling wheat variety with good disease tolerance and stable yields. Under favorable conditions, yields can exceed 10 t/ha. It is one of the three top Martonvásár wheat varieties grown in the most prominent areas, along with Mv Nádor and Mv Menrot. Agricultural Innovation Award winner in 2018. It is productivity of 9.00-10.5 t/ha. Its typical quality characterizations are hard kernel type, TKW is 45-50 g, crude protein content is 12-13%, wet gluten content is 30-32%, and farinograph group is A2. In addition, it has a good disease resistance level to stem rust, fusarium head plight, leave-plight, leave rust, yellow rust, and powdery mildew. The recommended fertilizer rate is 140-170 kg/ha of nitrogen as an active ingredient.

3.2 Agrotechnical Factors in Field Experiments

I. Forecrop: The crop grown in the field before the wheat experiment was the soybean, and sunflower was the forecrop of the maize experiment.

II. Tillage: The field soil was tilled using a disk and plow to incorporate the residue further into the soil. Afterwards, the soil was smoothed, and suitable seedbed prepped.

III. Crop Protection: Total herbicide (Mdalon) was applied for the maize field after planting in both years. For wheat crop, only on the first-year herbicide (Corte SE) was applied. Weeds were eliminated by hand when needed.

IV. Fertilization: The type, amount, and timing of fertilizers applied are specified as treatments for each experiment and detailed in the following sections.

V. Irrigation: Irrigation regimes, including timing and amount of water applied, are specified as treatments for each experiment and detailed in the following sections.

VI. Sowing: Sowing machine was used to sow wheat seeds on the 19^{th} of November 2021 and on the 19^{th} of November 2022. Planting machines were utilized to plant maize seeds by the conclusion of April. The planting density was 65000, with a row spacing of 75 cm and a within-row spacing of 20 cm.

VII. Harvesting: By the mid of July, wheat crop was harvested in both year with a combine machine. Maize yield was sampled by hand on the mid of October.

VIII. Crop Rotation: The sequence of various crops grown in the experimental field over time to improve soil health and reduce disease pressure was in this order: soybean – wheat – sunflower - maize.

IX. Meteorological status: Data and patterns of the meteorological status and climate overview and their elements are presented in the appendix.

3.3 Research Experiments

The research investigation was divided into a series of experiments:

3.3.1 Pre-Sowing Seed Priming Experiment

Martonvásár, the Center for Agricultural Research, supplied wheat seeds of the Mv Nemere and Mv Felleg varieties, and the Alföld was obtained from a producer. Priming solutions were prepared at a concentration of 600 ppm for the GAs and 80 ppm for the SA. The concentrations were determined based on a preliminary germination experiment that was conducted, which included two sets of concentration levels. Wheat seeds were treated with growth regulators GAs, SA, and distilled water three days before planting. They were soaked into the prepared solutions for 8 hours before air drying for two days. The three types of primed seeds of the three wheat varieties were sown in the field in the main 4 plots (total 9 sub-plots for each irrigation treatment). Irrigation was regularly given to the main plots according to the proposed durations. Hand hose sprinkler irrigation systems were used. Growth and yield parameters were monitored throughout the agricultural season, and data for different growth and yield parameters were recorded at various stages. Data regarding germination time, emergence time, seedling vigor, tillers number, plant height, and yield component, including spikes number, grain number per spike, and grain filling (thousand-grain weight (TKW)) were recorded.

After harvest, the grain yield was cleaned to remove impurities or foreign materials. Then, the yield was calculated, and the pre-test was made on the same harvest day using a Near-infrared (NIR) device, which provides data including protein content, gluten content, moisture percentage, and Zeleny index. The grain yield is stored for one month before conducting the quality tests to give enough time for the material composition and formation into the seed. Then, the quality examinations were conducted a month after harvest, including TKW, hectoliter weight, Zeleny index, gluten content using a gluten wash device, falling number, whole flour NIR test for moisture, protein, and gluten, and whole grain NIR test for Zeleny index, moisture, protein, and gluten

After data were collected for analysis, they were sorted according to the study proposal, checked for data validity, and run with statistical computing programs.

3.3.2 Germination Experiment

The present study examined the impacts of temperature, drought, waterlogging, and seedling density on germination's vigor and seedlings' development. Furthermore, an investigation into the inhibition of fungal growth was also conducted. The seeds of Alföld 90, a variety of Hungarian wheat widely cultivated in the region, and Margitta, a type of maize, were acquired from the Martonvásár research institute and subsequently utilized. The research was split into four experiments, which were carried out as described in the subsections below.

3.3.2.1 Temperature Sub-Experiment

This research examined the germination of six different temperatures: 5, 10, 15, 20, 25, and 30 ˚C for wheat and maize seeds at eight different temperatures: 5, 10, 15, 20, 25, 30, 35, and 40 °C. The media were prepared; the Petri dishes were labeled, and each one was filled with ten maize seeds and subjected to the same quantity of distilled water, 9 ml after the distilled water was tested for conductivity, which was 1.5 ohms/cm. The number of non-germinated seeds was counted, and all seedlings' radicle and plumule lengths were measured. Twenty wheat seeds per petri dish were used in this experiment. The measurement started when around 75% of the Petri dishes (PDs) seedlings reached a length of 1 cm. Daily, four Petri dishes were taken out of the chamber for physical measurements at each temperature level.

3.3.2.2 Water Amount Sub-Experiment

In sterile petri dishes with a 9 cm diameter lined with a single sterile filter paper, maize seeds were subjected to 13 distilled water amounts based on milliliter intervals and 16 distilled water amounts based on TKW. Wheat seeds were subjected to 12 distilled water amounts based on milliliter intervals and 13 distilled water amounts based on TKW. The TKW was obtained using a seed counter instrument, and it was 235.2 g for the maize and for the wheat seeds was 42.76 g.

Eq. I $$\text{TKW} * \text{Seed n}/100{,}000 = 1\% \text{ of the proposed water amount}$$

$$235.2 * 10 = 2352/100{,}000 = 0.02352 \quad \text{for the maize}$$
$$42.76 * 20 = 855.2,\ 855.2 / 100000 = 0.008552 \quad \text{for the wheat}$$

3.3.2.3 Seed Number Sub-Experiment

Four seed sets 10, 15, 20, and 25 for wheat were incubated in a germination chamber at a constant temperature of 20 °C, and 6, 8, 10, and 12 seeds per PD for the maize 20 °C and 25 °C. They were supplied with the same amount of distilled water, 6 ml for the maize and 7 ml for wheat. Ten replications were carried out for each treatment of each set to decrease the experiment's experimental error and increase the accuracy of the overall measurements. These classifications, maize, and wheat, were created to obtain an aggregated value following Equations II and III, respectively.

Eq. II $$\text{Aggregated value} = (\text{NO-G} * 0) + (S * 0.1) + (R * 0.25) + (SP * 0.65) + (NP * 1)$$

Eq. III $$\text{Aggregated value} = (\text{NO-G} * 0) + (R * 0.33) + (SP * 0.67) + (NP * 1)$$

where NO-G is non-germinated seeds, S is the start to initiate germination, R is the number of seeds germinated with radicle only, SP is the number of seeds germinated with short plumules, NP is the number of seeds germinated with normal plumule length.

3.3.2.4 Antifungal Experiment

to investigate which sterilization techniques fit the best for laboratory experiments, a fungicide, Amistar Xtra, in different concentrations, two different techniques, and Hypo were used to investigate their effect on inhibiting fungal growth in petri dishes. The active agents for this fungicide are 200 g/L azoxystrobin and 80 g/L cyproconazole, which Syngenta produces. The first technique was to apply 4 different concentrations of the fungicide, that is, 10, 100, 1000, and 10000 ppm, to the growth media. The other technique was to sterilize the seeds into the prepared solutions of 1000 ppm of Amistar Xtra and 5% of Hypo, separately, for 3 min; afterward, they were rinsed with distilled water. Two sets of ten replications for each treatment were incubated at 20 and 40 °C, respectively. Physical measurements and evaluations were conducted after the incubation period of 10 days. The petri dishes were taken out of the growth chambers, radicle length and plumule length were measured for all maize seedlings, and the number of germinated seeds was counted.

3.3.3 Effective Microorganisms Experiment

This factorial field experiment of effective microorganisms' application was conducted during the agricultural season of 2021-2022 as the first growing season. Seeds of wheat varieties of Alföld, Menrot, and Menrot were sown in the field on the 19th of November 2021. The experiment was designed following a Randomized Complete Block Design (R.C.B.D). Three replications for each treatment were implemented. The field was divided into two main sections and three sub-sections. Each sub-section has 9 plots. The plot (experimental units) dimeters is 1×4 m^2. The sub-sections were treated separately with either EM application, EM + N application, or N application. The N was applied on Feekes 10 (booting stage). The EM was applied at 0.125 ml of EM per square meter, 5ml:4L (EM:water) two days after ammonium nitrate application. The main section of the experiment was irrigated at the critical growth stages of water shortage, heading, and grain filling and ripening. Each time, the field was irrigated with 15 mm of water. The field map depicts the experimental setup.

Throughout the subsequent agricultural cycle, 2022 - 2023, the proposed plan underwent a process of development, updating, and modification. The present study incorporated the application of nitrogen doses. A total of six nitrogen doses, namely 0, 40, 80, 120, 160, and 200 kg/ha, were employed as an active agent of NH_4NO_3. On the 20th of November 2022, the field was sown with seeds of wheat varieties of MV Felleg. The experiment was conducted using the Randomized Complete Block Design

(RCBD) methodology. Three replications were conducted for each treatment. The field was partitioned into three distinct sections. The dimensions of the plot are 1 meter by 4 meters squared. The proposed dose of N was administered to all experimental units across all sections at Feekes 3. In the context of the EM application, the initial section was subjected to 0EM treatment, the subsequent section was subjected to a single instance of EM application at F3, and the final section underwent two instances of EM application at F3 and F6. The EM treatment was administered at a rate of 0.125 milliliters of EM per square meter, using a ratio of 5 milliliters of EM to 4 liters of water, two days following the application of ammonium nitrate.

The field was harvested for the first year on July 15th, 2022, and July 17^{th,} 2023, for the second year. The plots were harvested with a combine, and grains were put in labeled bags. Each bag's harvested yield was directly cleaned, weighted, and tested with whole grain NIR machine, and the estimated values of protein content, gluten content, moisture percentage, and Zeleny index were obtained. The harvested yield was stored for one month and then brought to the experimental lab belonging to the Agronomy Institute at the Hungarian University of Agriculture and Life Sciences. The quality tests were made as described at the end of this chapter. The tested wheat quality parameters were repeating the same whole NIR to provide the same four indexes and TKW, hectoliter weight, Zeleny index, gluten content using a gluten wash device, falling number, and whole flour and whole grain tests of moisture, protein, and gluten. The data were obtained, organized, tested for validity, and prepared for statistical analysis.

3.3.4 In-Crop N-Splitting-Timing Experiment

This study aimed to assess the in-crop nitrogen uptake, assimilation, and mobilization in wheat plants subjected to abiotic stress conditions. The comparison of morphological and quality parameters across different nitrogen application rates and timings enables the identification of the optimal nitrogen application strategy in the context of both drought and irrigation conditions. Furthermore, the outcomes of this study can provide valuable insights into crop management strategies, specifically pertaining to the application rates, timing, and division of nitrogen fertilizers. These strategies aim to enhance nitrogen use efficiency (NUE) and counteract the adverse impact of abiotic stress on crop productivity.

This factorial experiment was designed to investigate the effect of irrigation and nitrogen splitting on wheat growth, development, and quality. According to R.C.B.D, the field was divided into two main sections (irrigated and not irrigated), each split into three subsections: A single N application, two times N application, and three times N application. Each subsection contains 9 plots. The area of each plot is 4 m^2 (1 × 4 m). The first N application (NH_4NO_3) was applied at Feekes 3 (tillering stage), Feekes 6 (jointing stage), and Feekes 10 (booting stage).

Irrigation (20 mm of water) was implemented as necessary, particularly in instances of drought and high temperatures starting from stem elongation growth stage (Feekes 6). Various growth stages were assessed to determine vegetative growth traits, such as the number of plant tillers, plant height, and yield traits, including the number of spikes and grains per spike. In July 2023, the wheat crop was harvested using a combine.

Following the completion of the harvest, the grain yield underwent a cleaning process to eliminate any impurities or extraneous substances. Subsequently, the yield was computed, and the pre-test was conducted on the identical day of harvest utilizing near-infrared spectroscopy (NIR). Subsequently, the harvested grain yield was subjected to a storage period of one month prior to the commencement of quality assessments. This duration was allotted to allow for adequate material composition and seed formation processes to occur. Subsequently, a series of quality assessments were performed approximately one-month post-harvest. These assessments encompassed various parameters such as TKW, hectoliter weight, Zeleny index, gluten content determined through the utilization of a gluten wash device, falling number, NIR test of the whole flour with Dickey-John (InstaLab 600) to measure moisture, protein, and gluten levels, as well as NIR testing for both whole grain and flour samples to determine the respective NIR indexes. The methodology used to measure these traits will be elaborated upon in subsequent sections of this chapter.

3.3.5 Nitrogen Doses- Wheat Quality- Abiotic-Stresses Experiment

The field trial was conducted during the agricultural season of 2021-2022, with the plantation date set for the 19th of November, 2021. The experiment utilized the locally cultivated wheat variety known as Menrot. The surface area of each plot measures 4 m2 (1 × 4 m). The field map depicts the experimental setup. The NH_4NO_3 application, specifically at Feekes 10, was utilized to examine the impact of nitrogen application on crop yield and yield quality. After harvest, the grain yield underwent a post-harvest cleaning procedure intending to remove any impurities or extraneous substances. The yield was calculated, and the pre-test was carried out on the same day of harvest using NIR. Following this, the collected grain yield underwent a storage duration of one month before the initiation of quality evaluations. The allocated time frame was designated to facilitate the occurrence of sufficient material composition and seed formation processes. Following this, quality evaluations were conducted approximately one month after the harvest. The evaluations included a range of parameters, including TKW, hectoliter weight, Zeleny index, gluten content determined using a gluten wash device, falling number, NIR tests for measuring moisture, protein, and gluten levels, and NIR testing for both whole grain and flour samples to determine the respective NIR indexes. The subsequent sections of this chapter will provide a detailed explanation of the methodology employed to measure these traits.

3.3.6 Maize Field Experiment

The field trial was conducted during the summer growing season of 2022 and subsequently replicated on a larger scale during the summer growing season of 2023. This study aimed to examine various abiotic stressors that impact the performance of maize plants. The field was partitioned into irrigated and non-irrigated sections, delineated by borders both surrounding and separating them. In both years, the experimental treatments consisted of separate applications of nitrogen from different sources, namely organic (organic matter (OM) of N active agent of 9%) and conventional (ammonium nitrate (AN) N active agent of 34%), at a rate of 160 kg/ha N active agent in 2022. The study was developed in the following year, 2023, and fertilizer doses were introduced as a factor. The applied rates of N doses from both sources were 80, 160, 240, and 320 kg/ha active agents.

Also, effective microorganisms (EM) were applied individually and combined with the aforementioned nitrogen sources. These treatments and a control group were implemented in the field. The seeds of a regionally widely used variety of Hungarian maize called Margitta were obtained from a the Martonvásár research Institute.

In both years, the experimental planting machines were utilized to plant maize seeds by the conclusion of April. The planting density was 65000, with a row spacing of 75 cm and a within-row spacing of

20 cm. Following the random distribution of the experimental units among the sub-sections, the treatments were administered to the experimental plots, which were 3 meters, and replicated three times during the vegetative growth stage V4. The categories included in the study were control, EM, AN, GOM, EM + AN, and EM + GOM. The irrigated area received a consistent water supply of 20 mm every 5 days starting from the V4 growth stage. Weekly measurements were taken to assess various growth traits of the plant, including the number of leaves per plant, stem diameter, SPAD value, Quantum yield (QY) value, and plant height. For each plot, plant samples were chosen randomly to conduct measurements. Following the completion of the harvest, the recorded yield data was obtained, and the maize kernels were subsequently transported to the laboratory for quality testing.

3.4 Traits Measurements Methodology

Following is the description of the growth, yield, and yield quality of the tested traits in different sub-experiments:

I. Number of wheat tillers (spike/m^2): The tiller count was quantified by randomly selecting a representative sample of 10 wheat plants from each plot, and subsequently enumerating the number of tillers present on each plant. Tillers are the secondary shoots that emerge from the basal region of the wheat plant. To determine the average tiller number for each plot, the total number of tillers was divided by the number of plant samples (10). Subsequently, the values were transformed based on the measurement of wheat tillers per square meter.

II. Number of wheat spikes (spike/m^2): The measurement involved randomly selecting a 40 cm line segment and quantifying the number of spikes within this measured distance. The experiment involved conducting three repetitions for each plot and subsequently recording the mean values.

III. Number of wheat grains ($spike^{-1}$): A random selection of 5 wheat plants from each plot ensured the sample was representative. Subsequently, spikelets and grains per spikelet on each individual spike were quantified. The variability in the number of grains per spikelet is contingent upon the specific wheat variety and the applied treatments. The total quantity of grains in the sample was calculated by multiplying the number of spikes by the mean quantity of spikelets per spike and the mean quantity of grains per spikelet.

IV. Leaf area index (LAI): It measure light transmittance through the canopy and calculate LAI based on the light interception model using Sunfleck Ceptometers (AccuPAR 80, Decagon Devices, Pullman WA 99163 USA). Measure the LAI at multiple points within each plot at the respective growth stages (anthesis for wheat, flowering for maize).

V. SPAD: The photosynthesis activity measurements were conducted after randomly selecting 10 wheat plants and 4 maize plants from each plot. The photosynthesis activity of each plant was assessed by measuring both the lower and upper leaves and 3 leaves from the middle of the plant. These measurements were conducted using the SPAD device, and the resulting averages were recorded.

VI. Quantum yield (QY): It measures photosynthesis II efficiency. QY is equivalent to F_v / F_m in dark-adopted samples and F_v^1 / F_m^1 in light-adapted samples. The Photosynthesis System Instrument (PSI) was used for this measurement. The measurements with this FluorPen FP 110 were done after 20 minutes of blocking the photosynthesis activity with a special room adopter to measure in the dark.

VII. Leave number: The maize leaves were quantified weekly to discern variations in plant performance and growth rate across different conditions.

VIII. Stem diameter (cm): The stem diameter of maize plants was assessed using a Vernier caliper, precisely measuring from the lower portion of the stem, 10 cm above the ground. This measurement was taken to indicate the accumulation of cellulose, which indicates the plant's performance under different environmental conditions.

IX. Plant height (cm): After a random selection process, a representative sample of 10 wheat and 3 maize plants was obtained from each plot. The height of each plant, measured from the base of the stem to the head for the wheat and to the tip of the last leaf for the maize, was recorded using a scaled 2-meter wooden roller. Measuring the height on the same day and under similar weather conditions is imperative to maintain consistency. The recorded data included the height measurements for each plant in the sample. Subsequently, the determination of the mean height of the plants was conducted through the summation of all height measurements, followed by division by the sample size.

X. Weight of 1000 kernels (TKW) (g): 5,000 wheat and maize grains were enumerated using a seed counter machine. Subsequently, the 5000 grains of wheat or maize were measured in terms of weight utilizing a digital scale. Ultimately, the values were divided by a factor of 5 to derive the 1000-grain weight. A seed-counter instrument manufactured by Pfeuffer GMPH in Kitzingen, Germany, was utilized in this study.

XI. Hectoliter weight (test weight) (kg/hl): The weight of the wheat sample was measured in kilograms. The kilograms per hectoliter ($kghl^{-1}$) value was calculated by dividing the net weight by the volume of the hectoliter weight measuring device in liters, Eq. IV.

Eq. IV $$\text{Hectoliter weight } (kghl^{-1}) = (\text{Weight of filled hectoliter device - Weight of empty device}) / \text{Volume of hectoliter device in liters}$$

The calculated hectoliter weight represents 100 liters (1 hectoliter) of wheat. Higher hectoliter weights indicate typically denser and heavier grains, which are frequently associated with a higher protein content and a higher quality of wheat. Lower hectoliter weights may signify lesser kernels and a lower quality of wheat.

XII. Protein content (%): Wheat flour's protein content was measured using a near-infrared (NIR) grain analyzer. This analysis involved obtaining representative sub-samples of wheat grains from each harvested sample on two occasions: once on the day of harvest and again one month after the harvest day. The third iteration of protein quantification involved the utilization of a near-infrared (NIR) flour analyzer, specifically the DICKEY-John model. To prepare the wheat grains for analysis, they were finely ground into a powder using a milling apparatus. Subsequently, the flour was introduced into the near-infrared (NIR) machine. The percentage of protein was determined.

XIII. Gluten content (%): A quantity of ten grams of the wheat flour sample was measured and transferred into a small kneading bowl. Subsequently, 5 ml of distilled water was introduced into the beaker and agitated to produce a cohesive mixture resembling dough. The dough underwent a 30-second kneading process using a vibrating kneader device, resulting in a smooth texture. Subsequently, the dough was subjected to a gluten washer, which underwent a washing process utilizing running water containing 2% sodium chloride (NaCl) for 20 minutes. The gluten that had been washed was subsequently gathered on filter paper, and its weight was determined following a centrifugation process lasting 2 minutes. Subsequently, the gluten sample was weighed, and the corresponding measurements were duly documented. Sadkiewicz Instruments is a brand associated with the bakery industry LTD research institute (ZBPP). This brand specializes in producing various instruments used in gluten analysis, including the gluten wash machine, vibrating kneader (type sz-1), and the gluten centrifuge.

XIV. Falling Number, Hagberg number (second): The wheat grain under examination was ground according to the specifications outlined in the PN-ISO 3093 standard, as any deviation from the prescribed procedure may impact the outcome of the test. A 7-gram analytical sample of the flour was obtained for testing, with a moisture content of 15%. The analytical sample was transferred into the viscometric test tube with 25 ml of distilled water, maintaining a temperature of 20±5 C. The test tube was sealed using a rubber stopper, and the sample was manually agitated for 20 seconds using vertical and horizontal movements to achieve a uniform mixture. The closure was removed, and the stirrer was inserted into the test tube, effectively scraping the flour from the inner walls of the test tube and incorporating it into the slurry. The test tube, equipped with a stirrer, was carefully immersed in the boiling water bath tank of the falling number device. Following a duration of 60 seconds, the stirrer was automatically disengaged from the drive unit, and subsequently, the obtained results were documented. The instrument utilized for the falling time assays is manufactured by Sadkiewicz Instruments (ZBPP).

XV. Near-infrared (NIR) Tests: Two different NIR instruments were used, the NIR for grain analyzer and the NIR for flour analyzer. The grain analyzer was used after preparing a clean sample, filling the instrument's glass container, and placing it into it. Within about 2 minutes, the results of Gluten content, moisture percentage, protein content, and Zeleny index were obtained and recorded in the prepared Excel file. NIR flour analyzer (DICKEY-john) was used after grinding the grain with a mill, placing the flour into the testing tool, and placing it into the device. The values of moisture percentage, protein content, and gluten content of the flour were obtained within 3 minutes. These values were recorded in the prepared Excel file.

3.5 Statistical Analysis

The results and data presented are expressed as a mean value for each sub-experimental section. Analysis of variance (ANOVA) and Fisher’s test of least significant differences were used to determine significant differences at the 5% probability level for the water quantity experiment, seedling density experiment, and antifungal growth experiment using computing programs (GenStat twelfth edition, GenStat Procedure Library Release PL20.1m, and MS Excel 365). A sigmoid curve model was applied using statistical computing programs (J.M.P. Pro 13.2.1 of S.A.S. by SAS Institute, Canberra, the USA, and MS Excel 365) to fit the data and plot the best-fit temperature levels. The data were checked for normality using Skewness and Kurtosis in SPSS v27, IBM, New York, the USA.

4 RESULTS AND THEIR DISCUSSION

This study investigates the impact of abiotic factors, such as drought or heat and waterlogging stresses, on the germination, crop establishment, growth, and development across different life stages of wheat (*Triticum aestivum* L.) and maize (*Zea mays* L.) in field and laboratory conditions. The findings of this study enhance our comprehension of how plants react to abiotic stresses and aid in developing novel strategies. Thus, it is essential to investigate the plant stress tolerance mechanisms to identify novel management components and techniques for enhancing crop resistance and tolerance. Hereafter the result will come just in the order of each experiment described in the last chapter.

4.1 Pre-Sowing Seed Priming Experiment

Seed priming with gibberellin (GAs) and salicylic acid (SA) to encounter abiotic stresses of drought and waterlogging and heat tolerance of wheat. Seed priming technology, which means soaking the seeds before sowing, with plant growth regulators to benefit linked between the stimulation process of seed germination and the germination process itself. It can improve and homogenize emergence, giving a robust homogeneous arrangement and better early field foundation. The pre-adaptation response may help counter various stresses present, including water shortage and waterlogging, thus reducing the damage caused by this stress on the plant's growth and yield. Moreover, this technology is simple, cost-effective, and risk-free. The experiment aims to determine the varying responses of wheat cultivars to stimulus parameters.

Based on the Hungarian environment for wheat production, it is evident that irrigation of 20 mm every 6 days is beneficial during the vegetative growth stages during a dry year, particularly during stem elongation stages (Feekes 6 to Feekes 10). This irrigation regimen is crucial for enhancing plant biomass, photosynthesis activity, and, finally yield quantity. Additionally, irrigation every 3 days during the grain-filling and stage is essential for improving quality aspects such as protein content, gluten content, and sedimentation volume. Seed priming with gibberellic acid and salicylic acid has a notable beneficial impact on enhancing plants' ability to withstand drought-induced abiotic stress. They enhanced several traits related to plant growth and crop productivity, such as the overall yield, weight of individual grains, number of plant tillers, number of spikelets per plant shoot, gluten content, and Zeleny index. The planted varieties exhibited notable differences in performance, with the newer varieties Menrot and Felleg outperforming the historic local variety Alföld in their resistance to drought stress.

4.2 Germination Experiment

4.2.1.1 Maize

Germination and seedling development are essential stages in a plant’s life cycle, greatly influenced by temperature and moisture conditions. The aim of this study was to determine maize (*Zea mays* L.) seeds’ germination and seedling development under various abiotic stresses. Eight dif-ferent temperature levels, 5, 10, 15, 20, 25, 30, 35, and 40 °C, were used. Drought and waterlogging stresses were tested using 30 water levels based on one-milliliter intervals and as percentages of thousand kernel weight (TKW) at 20 and 25 °C. Seedling density and the use of antifungals were also examined. Temperature significantly affected germination duration and seedling growth, and 20 °C was found to be ideal with an optimal range of less than 30 °C. Germination occurred at 25% of the TKW. The optimal water range for seedling growth was higher and broader than the range for germination. Seed size assisted in defining germination water requirements and providing an accurate basis. The present research established an optimum water supply range of 150–325% of the TKW for maize seedling development. A total of 6 seeds per 9 cm Petri dish may be preferable over greater densities. The technique of priming seeds with an antifungal solution before planting was observed to have a better effect than applying it in the growth media.

4.2.1.2 Wheat

Temperature and moisture are essential factors in germination and seedling growth. The purpose of this research was to assess the germination and growth of wheat (*Triticum aestivum* L.) seeds under various abiotic stressors. Six distinct temperature ranges were used: 5, 10, 15, 20, 25, and 30 °C. Stresses of drought and waterlogging were quantified using 25 water levels based on single-milliliter intervals and as a percentage based on thousand kernel weight (TKW). Seedling density was also tested. Germination duration and seedling growth were impacted significantly by temperature, and a temperature of 20 °C was observed to be optimum, and an optimal range bordered at 15 °C to less than 25 °C. The seed germinated at a water amount of 75% of the TKW, and its ideal range was lower and narrower than the range of seedling development. Seed size provided an objective basis for defining germination water requirements. The current study established an optimal water supply range for wheat seedling growth of 525–825 percent of the TKW. Fifteen seeds within a 9 cm petri dish may be preferred to denser populations.

4.3 Effective Microorganisms Experiment

4.3.1 2021-2022

The findings of the current investigation revealed a statistically significant positive linear correlation between irrigation (20 mm of water after heading weekly) and production of wheat Figure 4.1. On average, in overall treatments, the irrigated wheat field produced a significantly higher grain yield by 35.45%, 3091 kg/ha, than the non-irrigated one, 2160 kg/ha. There were significant variations among the treatments: the combination of EM + N resulted in the highest grain yield, 3125 kg/ha, which is significantly higher than other treatments. Nitrogen treatment led to a statistically significant increase in grain production, with a mean value of 2861 kg/ha. The EM treatment resulted in significantly higher grain yields by 11.11% of 2384 kg/ha than the control 2133 kg/ha, respectively. This implies that effective microorganisms play a role in improving plant performance and countering abiotic stresses, particularly drought stress. The result shows an interaction between the EM and the nitrogen application. Separately or in combination, it helps plant strength at different levels, ultimately resulting in increased resistance to the surroundings to the abiotic stresses.

Genetic environment (G*E) interaction among wheat varieties presents apparent variations. Some varieties, Menrot and Nemere yielded significantly greater values of 2938 kg/ha and 2899 kg/ha than Alföld 2041 kg/ha as an average across the irrigation system and treatments. The relationship between genotype and environment was evident in the Alföld variety, as shown by a significant increase in yield of 1261 kg/ha with irrigation. This implies that local variety has the potential to achieve higher yields within various ranges when environmental conditions align with the needs of the varieties or when specific treatments are used to alleviate the adverse impacts of environmental pressures.

This experiment in the planting year of 2021-2022 of applying N, EM, and their combination along with the control in irrigated and not irrigated fields provided innovative and unique insights into addressing abiotic stressors in agriculture, especially drought. Irrigation has a significant positive impact on wheat yield quantity and quality. On average, the in-crop use of EM + N + irrigation demonstrates a significant enhancement in crop production and improvements in several quality indicators. The use of EM applications has been seen to provide beneficial outcomes in enhancing the resilience of crops against the adverse effects of drought and heat conditions, although to varying extents. The in-crop application of EM has not been used by any researcher so far, and this discovery is significantly adding to the existing scientific information of the knowledge body of science.

4.3.2 2022-2023

Statistics indicate that the use of effective microorganisms (EM) has a significant impact on wheat productivity. The grain production was improved by 25.05% after applying the EM twice, at F3 and F10. However, based on the data, it seems that the second application time, EM at F10, was more successful in increasing field output than a single application time at F3 since there was a significant difference. The EM plays a crucial function in aiding the plant's resilience against moisture deficiency. However, as there is no evidence of their impact on the grain yield when applied solely at F3, it may be attributed to the need for the EM treatment for a soil temperature of about 17°C at the time of application. The temperature optimization may be achieved during the latter stages of the plant's life, namely in April in Hungary. The temperature at the moment of application may have a significant impact on the microorganisms themselves, whether it is low or high.

Based on this experiment, it can be concluded that applying EM twice at F3 and F10 has a very advantageous impact on significantly increasing the yield by 25.05% and improving the yield quality, particularly the protein content, by 3.35%. The application of EM mainly contributes to production by raising the number of tillers per plant by 14.08% and the number of spikelets per spike by 6.84%, resulting in an overall increase in yield. Applying nitrogen at 160-200 kg per hectare significantly increases all vegetative and yield metrics. Repectvelly, grain yield had a significant increase of 47.19% and 54.40%, leaf area by 85.10% and 85.10%, plant tillers by 32.25% and 47.05%, spikelets number per spike by 20.740% and 22.71%, plant height by 19.90% and 21.73%, and protein content by 10.78% and 11.51%. These statements may be summarized as follows: they result in the development of a more robust and resilient plant capable of enduring abiotic stressors and producing under drought.

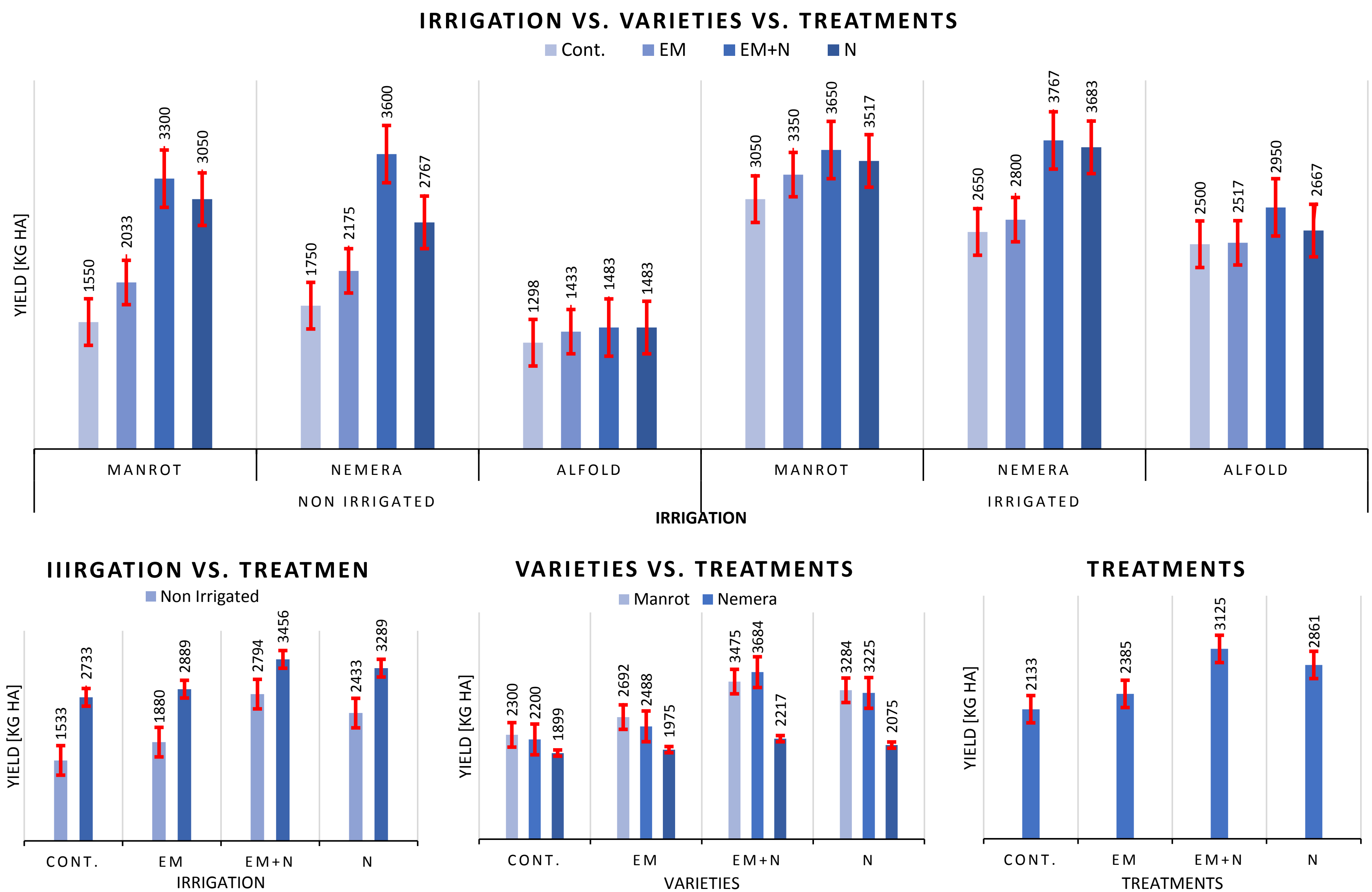

Figure 4.1. Yield production kg/ha under drought stress and different treatments of different varieties of *Triticum aestivum* L.

In-Crop N-Splitting-Timing Experiment

The statistical study reveals a robust positive impact of N-splitting on wheat grain yield, namely at the critical development stages of F3, F6, and F10. When splitting and applying the identical nitrogen N dosage of 160 kg/ha into three doses (F3=53.33, F6=53.33, and F10=53.33) kg/ha, there is a substantial increase in the ultimate grain yield by 5.20% compared to using just two doses (F6=80 and F10=80) kg/ha. This gain is also statistically significant compared to applying the total quantity of nitrogen 160 kg/ha in F3 by 2.45%. This means that nitrogen management is crucial in enhancing plant vigor and resilience to abiotic stressors. Furthermore, it implies that the wheat plant must be improved before the growth stages, which will have a greater impact on the yield components. This can be achieved by enhancing the plan to increase the number of plant tillers, spiks, spikelets, and, ultimately, grain filling. The success of this enhancement process relies on the genetic capacity of the plant and its interaction with the environment, mainly because yield is a quantitative trait. It is well known that the physiological component of yield is determined by the multiplication of the number of tillers, the number of spikelets per spike, and the grain filling (TKW).

Data shows that irrigation greatly enhances the plant's capacity to withstand the adverse impact of drought-induced abiotic stress, resulting in a 12.573% increase in ultimate grain production. This improvement was seen across several N-splitting treatments and different wheat varieties, with the yield rising from 6216 kg/ha in the non-irrigated field to 7050 kg/ha in the irrigated area. Therefore, these findings suggest that irrigation is beneficial to be applied in a dry year in a Hungarian environment starting from Feeks 6, with a water amount of 20 mm, every week during the dry periods is characterized by low raifull.

The cultivated wheat varieties exhibit substantial variation in their sensitivity to drought, N application, and irrigation and their genetic capacity to endure stressors. Statistics indicate that Neremre variety achieved a much higher grain yield than Felleg by 20.17% and 35.26% compared to Alföld. Despite notable variations among contemporary wheat varieties, they exhibit superior resistance to drought stress compared to the older Alföld variety, which yielded a mere 5536 kg/ha across all treatments.

The best management compilation of this experiment in terms of gain yield resulted in 8433 kg/ha when using the wheat variety of Nemere, splitting the same amount of N in three dosages, and irrigating with 20 mm water starting from Feeks 6 every week during the dry periods is characterized by low raifull. Therefore, to mitigate the effect of abiotic stresses, especially drought, this experiment suggests using modern-produced varieties along with a good strategy of N application by siplitting it into doses and irrigating the plant when needed, especially in the critical growth stages.

This study is crucial for addressing the management strategy of nitrogen usage, application and timing, and irrigation to mitigate the abiotic stresses caused by drought and heat. The plant growth, grain yield, and wheat quality parameters were significantly enhanced by implementing a nitrogen splitting strategy, which involved dividing the nitrogen into three portions and applying them during critical growth stages that directly influenced the final yield. These growth stages include tillering (Feekes 3), stem elongation and canopy development (Feekes 6), and spikelet formation followed by grain filling (Feekes 10). The results demonstrated a superior outcome when the same total quantity of N was applied compared to applying it all at once in F3 or dividing it across F3 and F6. The grain production, protein content, gluten content, and number of spikelets per spike showed a significant rise.

Nevertheless, some traits, such as plant height and leaf area index, were significantly diminished due to splitting nitrogen doses. This outcome is comprehensible since these parameters need a complete initial N dosage to achieve higher values. Hence, this strategy is efficacious in alleviating the effects of drought stress and enhancing nitrogen use efficiency. Providing a substantial amount of nitrogen during the grain-filling stage would further improve the quality of wheat grains and flour. In the Hungarian environment, irrigation of 20 mm weekly is beneficial during the dry period, typically during the booting, shooting, and grain-filling phases when there is little to no precipitation. There was a notable disparity among the cultivated wheat varieties in their resistance to drought and heat conditions, with newer produced varieties, such as Nemere, exhibiting more resistance than the older variety, Alföld. However, the variety that exhibits a larger grain yield is associated with a lower protein percentage, and vice versa.

4.4 Nitrogen Doses- Wheat Quality- Abiotic-Stresses Experiment

The data obtained indicate the presence of statistically significant differences among the N treatments of 0, 40, 80, 120, 160, and 200 kg/ha of N active agent, using NH_4NO_3. However, these differences are not apparent in a coherent fashion. It seems that applying nitrogen fertilizer in late growth stages on the heading stage and after has no positive effect on grain yield quantity of wheat under extreme drought and heat stresses. That it is, higher N application rates 120, 160, and 200 kg/ha of N active agent present statistically no increase in the yield; nevertheless, lower to non-N applications present a better performance in terms of yield quantity, for example, 80 kg/ha N, present significantly higher yield 3350 kg/ha than more considerable N application rate, for example, 200 kg/ha N, 2950 kg/ha. It suggests that high nitrogen dosage increases the negative pressure on the crop. This study provides evidence that administering fertilizers during the latter stages of the crop's life cycle, particularly under drought and heat stress conditions, has a detrimental impact on the overall yield amount.

The changes in the protein and gluten composting continue subsequent to the harvest. Therefore, part of this study follows the changes in the protein, gluten, sedimented materials, and moisture at three post-harvest points: harvest day grain measurement and grain measurement after a month of the harvest day. The results present an increase in the protein and gluten contents of the grains. Protein values, for example, for the N treatments of 0, 40, 80, 120, 160, and 200 increased respectively from 9.17 to 10.8, 11.23 to 11.50, 14.30 to 13.43, 13.17 to 14.34, 14.90 to 15.00, and 14.54 to 16.03%. These parameters present the biochemical changes in the wheat grains starting from the day of harvest to a month after to give enough time for the materials inside the grain to continue forming. However, the SDS volume values decreased during this duration, The moisture was increased during this time duration according to the data, which refers to the dry season, and the grain was below the required moisture level at harvest because of the extreme dry season.

Yield was positively correlated with the TKW, HLM, and moisture but negatively correlated with protein, gluten, and SDS. This is logical and consistent with studies by other researchers (Balla et al., 2011; Eser et al., 2020; Le Bourgot et al., 2023; Nuttall et al., 2017; Plant et al., 1981; Tomaz et al., 2021). However, regardless of yield, TKW, and HLM, the quality parameters, including protein, gluten, and SDS, were significantly correlated positively.

This study provides evidence that administering fertilizers during the latter stages of the crop's life cycle, particularly under drought and heat stress conditions, has a detrimental impact on the overall yield amount. The finding of this study suggests that management under abiotic stresses can improve the value of HI and obtain a higher yield, for example, by applying N fertilizers not only at the reproductive stage of the plant life cycles but also at the vegetative growth stages such as tillering stage Feekes 3 and also stem elongation stage Feekes 6. Moderate N application at this stage during abiotic stresses also increases the grain quality, including the protein and the gluten contents. However, a high rate of N application increases extreme abiotic stresses (drought stress) on wheat plants and negatively impacts the yield quantity.

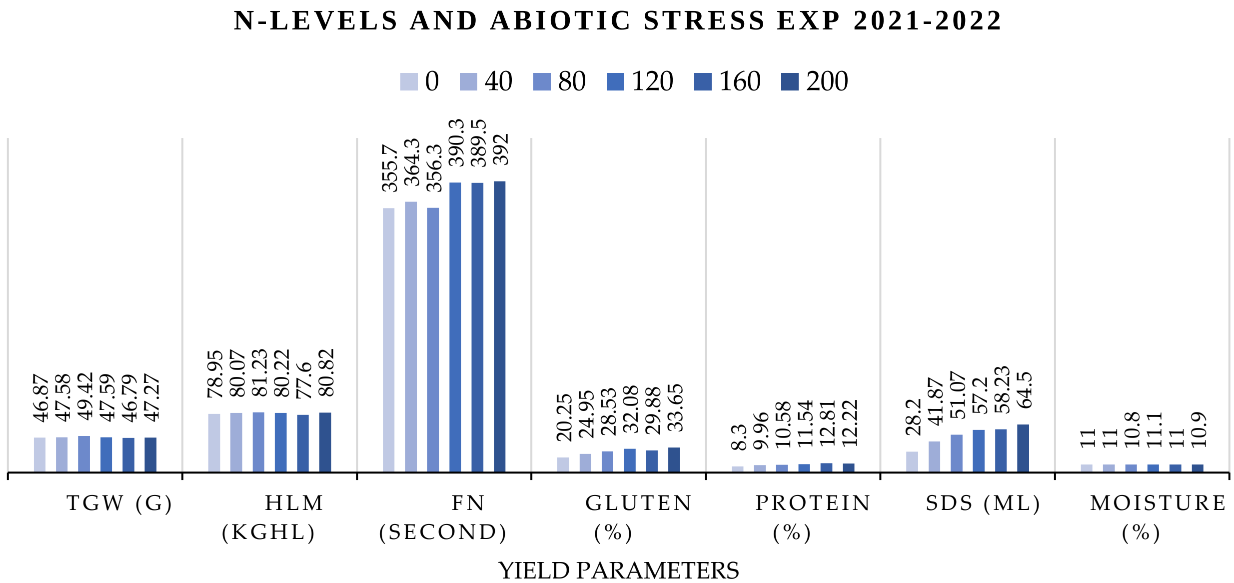

Figure 4.2. Parameters relating to the production and quality of *Triticum aestivum* L. responding to different levels of nitrogen application under drought and heat stresses in 2021-2022.
TKW is the -thousand-grain weight measured with seed counter machine and weight (g); HLM is the Hectolitre mass (test weight) measured as kilogram per hectoliter (kg/hl); FN is the falling number (α-amylase activity) measured per time (second); gluten percentage of the white flour measured by gluten wash machine; protein content of the whole flour measured with NIR (%); moisture level of the whole flour measured with NIR (%); SDS is the sedimentation volume (Zeleny Test) of the whole grain measured with NIR (ml).

4.5 Maize Field Experiment

In Hungary, the year 2022 saw severe aridity, while the following year, 2023, exhibited average precipitation levels. An almost negligible harvest was achieved in the year 2022. Nevertheless, a substantial yield was accomplished in 2023. Despite the early implementation of irrigation in the irrigated field on a weekly basis, there were no significant differences in kernel production compared to the non-irrigated area. Nevertheless, there was a statistical increase with irrigation by 8.39%. The data revealed a notable interaction between the irrigation and the treatments. Irrespective of the nitrogen source used, it led to a substantial increase in the kernel yield compared to the control. This is due to nitrogen's role as a vital macronutrient for plant activity and serves as a fundamental constituent of amino acids, which constitute the basic units of plant proteins and enzymes. Proteins are the structural components of plants, whereas enzymes enable a wide range of metabolic processes in plants. Nitrogen is also a chlorophyll molecule component, allowing the plant to capture sunlight energy by photosynthesis, driving plant growth and maize kernel yield shows a significant difference between the N sources, namely the chemical and organic sources. Applying NH_4NO_3 at a rate of 160 kg per hectare resulted in a kernel yield of 16838 kg per hectare, whereas the organic source yielded 8458 kg per hectare, with a percentage difference of 66.25%.

Nevertheless, no significant variations were seen between the nitrogen sources when greater levels of nitrogen application, namely 240 and 320 kg/ha, were used. This implies that more organic-based applications are required to achieve a higher crop yield. This can be attributed to the gradual release of nitrogen and the rate at which organic matter decomposes, which can be influenced by various factors such as moisture, temperature, and types of microorganisms present.

The use of efficient microorganisms led to a substantial increase of 67.44% in maize kernel output, reaching 9773 kg/ha, compared to the control group, which yielded 4844 kg/ha. Using EM treatments in conjunction with OM fertilizer demonstrates a significant statistical improvement in kernel production compared to its combination with chemical fertilizer. Nevertheless, the simultaneous use of EM and fertilizer does not substantially impact maize kernels' production in irrigated and non-irrigated areas. This implies that EM treatment might somewhat mitigate plant stress when used alone, but other factors, such as the presence of fertilizers, may overshadow its impact.

Based on the data, it can be inferred that irrigation does not significantly affect kernel production in Hungary during an average precipitation year. However, applying EM (effective microorganisms) can slightly enhance the yield compared to the control group. Furthermore, the chemical nitrogen source NH_4NO_3 has a greater influence on the yield than the organic source but using a high amount of OM can show a better performance.

It can be shown that irrigation has no substantial impact on kernel yield in Hungary during a typical year of precipitation. However, in a year with low rainfall, irrigation of at least 20 mm per week is required starting from V6 growth stage to achieve yield and alleviate the effects of drought stress. Nevertheless, using the EM may somewhat improve the yield compared to the control. In addition, the chemical nitrogen source NH_4NO_3 has a more significant impact on the yield than the organic source. However, using a large quantity of organic matter might improve performance. Individually or in combination, the application of NH_4NO_3, OM, and EM has a statistically significant positive impact on various growth and quality traits, including kernel yield, cobs yield, cobs number, empty cobs yield, number of kernels per cob row, number of kernels per cob column, SPAD and LAI values, starch content, protein content, oil content, and yield moisture content. The application of 160 kg/ha of NH_4NO_3 and OM range of 160 to 240 kg/ha resulted in a more favorable outcome than higher levels of 320 kg/ha, which negatively influenced most growth parameters, particularly in the non-irrigated area. The plant could not achieve an optimal result when the amount of N treatment was lower than 160 kg/ha. When applying fertilizers containing N active agents, it is essential to consider environmental parameters, particularly moisture availability and the presence of decomposing microbes. This is because many biotic and abiotic factors may influence the breakdown of organic matter. Consequently, a larger dosage of organic matter is recommended to be used compared to artificial N sources to enhance the release and availability of nitrogen to the plant roots in the rhizosphere area.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

I. Laboratory Germination Experiments

A. The sigmoid curves have a solid fit for the experimental data of germination and seedling growth temperatures. The optimal temperature for maize seedling growth is 20 °C, and a more comprehensive range for germination is from 20 to 35 °C. For wheat, 20 °C was ideal for seedling development. Wheat germination has a broad range of 20 °C to 30 °C. A temperature lower than the optimal range decreases the germination rate, and a higher temperature increases fungal growth for both crops.

B. Seed size influences the quantity of water needed for germination. Therefore, TKW provides a more accurate perspective for water amount application. Maize germination in different percentages can occur in a wide range of water amounts starting at 0.60 ml, representing 25% of the maize TKW, but the optimal range for germination is 0.06–5.30 ml, representing 25–225% of the TKW. The optimal range for seedling growth is 2.35–7.75 ml. As the temperature increases, the optimal range for the water amount narrows; e.g., at 20 °C, it is broader than at 25 °C. For wheat, germination of various percentages can occur in a broad range of water quantities commencing at 0.65 ml, which represents 75% of TKW, but the optimal range for germination is 4.45–7.00 ml, representing 525–825% of the TKW.

C. Dry weight can indicate seedling development because dry matter accumulation is consistent with the physical measurement of seedling growth.

D. Different seed and seedling densities present no significant difference; thus, a lower seed density is recommended for lab examination: 6 maize seeds and 15 wheat seeds per 9 cm Petri dish. This is common practice in the case of seed limitation and breeding projects.

E. The seed priming technique before planting shows a significantly better effect on seedling growth than adding the antifungal to the growth media, and the highest values were recorded with the control.

This conclusion is supported by a other laboratory optimization studies conducted by Tarnawa et al,. (2023), Haj Saghaier et al., (2022).

II. Pre-sowing seed priming experiment

Considering the conditions in Hungary for growing wheat, it is clear that irrigation of 20 mm every 6 days is beneficial starting from Feeks 6 throughout the vegetative development phases, especially during the stem elongation stages (Feekes 6 to Feekes 10). Implementing this irrigation regimen is essential for optimizing plant biomass, promoting photosynthetic activity, and ultimately increasing crop amount.

For instance, research conducted by Pálmai et al. (2017) found that regular irrigation during the vegetative phase significantly enhances biomass accumulation and photosynthetic efficiency, which in turn increases the overall yield of wheat crops. This is corroborated by Steduto et al. (2012), who emphasized the critical importance of sufficient water supply during key growth stages to maximize biomass and yield potential in cereals. Furthermore, it is necessary to engage in irrigation every 3 days throughout the grain-filling stage to enhance quality attributes such as protein content, gluten content, and sedimentation volume, which is aligns with findings from other studies. For example, Leilah et al. (2015) demonstrated that increased irrigation frequency during the grain-filling period significantly improves grain quality parameters, such as protein and gluten content, which are critical for bread-making quality. Similarly, Saini and Westgate (2000) found that adequate water supply during grain-filling is crucial for maintaining grain quality, particularly under conditions of environmental stress, reinforcing the importance of the proposed irrigation regimen.

Applying gibberellin and salicylic acid to seeds significantly improves plants' resistance to drought-induced abiotic stress. They improved several traits associated with plant development and agricultural production, including total yield, weight of individual grains, number of plant tillers, number of spikelets per plant shoot, gluten content, and Zeleny index. The enhancement of plant agronomic traits this study found is consistent with existing literature. According to Khan et al. (2015), the application of gibberellin and salicylic acid enhances drought tolerance by modulating stress-responsive pathways, leading to improved water-use efficiency, increased yield, and better grain quality under drought conditions. Moreover, Anjum et al. (2011) reported similar improvements in drought resistance and agronomic traits, including total yield and grain quality, when wheat seeds were treated with these PGRs, highlighting their efficacy in mitigating the adverse effects of drought.

The planted varieties have shown significant variations in performance, with the more recent cultivars Nemere and Felleg surpassing the traditional local variety Alföld in their ability to withstand drought stress. This finding of the current study is consistent and supported by studies on varietal performance under similar conditions. For instance, Szira et al. (2008) reported that newer wheat varieties bred for drought tolerance exhibit superior performance in terms of yield stability and quality under water-limited conditions compared to older, traditional varieties. Similarly, Fischer et al. (2012) highlighted the advancements in wheat breeding that have led to the development of cultivars with enhanced drought resilience, which are better equipped to maintain productivity and quality under stress conditions.

III. Effective Microorganisms Experiment

A. 2021-2022 experiment

Irrigation has a significant positive impact on wheat yield quantity and quality. N, EM, and their combination, along with the control in irrigated and not irrigated fields, provided innovative and unique insights into addressing abiotic stressors in agriculture, especially drought. On average, the in-crop use of EM + N + irrigation demonstrates a significant enhancement in crop production and improvements in several quality indicators. The use of EM applications has been seen to provide beneficial outcomes in enhancing the resilience of crops against the adverse effects of drought and heat conditions, although to varying extents. The in-crop application of EM has not been used by any researcher so far, and this discovery is significantly adding to the existing scientific information of the knowledge body of science. The finding that the application of effective microorganisms improves the ability of crops to withstand drought and high temperatures is consistent with the research conducted by Xu et al. (2011). Xu et al. found that EMs may boost plant resistance to environmental stress factors by promoting root development and increasing water retention in the soil.

B. 2022-2023 experiment

Based on this experiment, it can be concluded that applying EM twice at F3 and F10 has a very advantageous impact on significantly increasing the yield by 25.05% and improving the yield quality, particularly the protein content, by 3.35%. The application of EM mainly contributes to production by raising the number of tillers per plant by 14.084% and the number of spikelets per spike by 6.84%, resulting in an overall increase in yield. Applying nitrogen at a rate of 160-200 kg/ha leads to a considerable rise in all vegetative and yield metrics. Respectively, grain yield had a significant increase of 47.19% and 54.40%, leaf area by 85.10% and 85.10%, plant tillers by 32.25% and 47.05%, spikelets number per spike by 20.74% and 22.71%, plant height by 19.90% and 21.73%, and protein content by 10.78% and 11.51%. These statements may be summarized as follows: they result in the development of a more robust and resilient plant capable of enduring abiotic stressors and producing under drought. This finding is in line with the research conducted by Chen et al. (2006). They found that the combination of effective microorganisms and conventional fertilizers can enhance plant resilience and productivity in stressful environments.

IV. In-Crop N-Splitting-Timing Experiment

The plant growth, grain yield, and wheat quality parameters were significantly enhanced by implementing a nitrogen splitting strategy, which involved dividing the nitrogen into three portions and applying them during critical growth stages F3, F6, and F10. Hence, this strategy is efficacious in alleviating the effects of drought stress and enhancing nitrogen use efficiency, which is aligns with findings from other studies. For example, Fageria and Baligar (2005) demonstrate the importance of nitrogen time applications to elevate NUE and endure drought abiotic stress, which leads to improve plant growth and yield. Providing a substantial amount of nitrogen during the grain-filling stage would further improve the quality of wheat grains and flour, which is supported by the finding of Barraclough et al. (2010), which present that late nitrogen applications improve grain quality. In the Hungarian environment, irrigation of 20 mm weekly is beneficial during the dry period, typically during the booting, shooting, and grain-filling phases when there is little to non-precipitation. There was a notable disparity among the cultivated wheat varieties in their resistance to drought and heat conditions, with newer produced varieties, such as Nemere, exhibiting more resistance than the older variety, Alföld. This is supported by Reynolds et al. (2009), who demonstrated that newer wheat varieties bred for drought resistance outperform older varieties under unfavorable climatic conditions.

V. Nitrogen Doses- Wheat Quality- Abiotic-Stresses Experiment

This study provides evidence that administering fertilizers during the latter stages of the crop's life cycle, particularly under drought and heat stress conditions, has a detrimental impact on the overall yield amount. Moderate N application (80 to less than 120 kg/ha^{-1}) at this stage during abiotic stresses also increases the grain quality, including the protein and the gluten contents. However, the high rate of N application (120 kg/ha and more) increases extreme abiotic stresses (drought stress) on wheat plants and negatively impacts the yield quantity. The finding that high nitrogen fertilization (≥120 kg/ha) exacerbates drought and heat stresses and reversely affects yield is consistent with the study by Fageria et al. (2010), who demonstrate that excessive N application under stress conditions, can increase the plant's susceptibility to abiotic stresses. Furthermore, Barraclough et al. (2010), supported our finding when stating that appropriate N levels improve quality parameters of the final product of wheat without negatively impacting yield quantity.

VI. Maize Field Experiment

In maize production, irrigation does not significantly affect kernel yield in Hungary under average annual precipitation conditions. Nevertheless, during a year characterized by little precipitation, it is necessary to apply irrigation of no less than 20 mm per week starting from growth stage of V6 to attain optimal crop production and mitigate the negative impacts of drought-induced stress. According to studies by Olesen et al. (2011), supplementary irrigation is crucial for sustaining maize output under drought circumstances, which supports the conclusion of the current study. However, Traore et al. (2009) demonstrate that maize yield responses to irrigation varied depending on water availability, indicating that under normal precipitation, irrigation may not substantially influence production.

However, using the EM application technique may somewhat enhance the yield compared to the control. This finding is in line with with the finding of Higa and Parr (1994), who stated that effective microorganism's application can enhance soil health and crop yields.

Furthermore, the chemical nitrogen source NH_4NO_3 has a more pronounced influence on the yield than the organic source. Nevertheless, using a substantial amount of organic matter may enhance efficiency. The conclusion is supported by study of Fageria et al. (2010), which demonstrate that chemical nitrogen source typically gives a more immediate and higher nutrient availability than the organic sources. Nevertheless, the beneficial impact of organic nutrient source (organic matter) for enhancing soil health and nutrient efficiency were pointed by Liebig et al. (2004), who stated that organic sources of of fertilizers can enhance long-run soil fertility and crop yield. The application of NH_4NO_3, OM, and EM, individually or in combination, has a statistically or significant positive effect on a range of growth and quality traits. These include kernel yield, cobs yield, cobs number, empty cobs yield, number of kernels per cob row, number of kernels per cob column, SPAD and LAI values, starch content, protein content, oil content, and yield moisture content. Applying 160 kg/ha of NH_4NO_3 and a range of 160 to 240 kg/ha of organic matter had a more positive effect than higher levels of 230 kg/ha. The higher levels negatively affected most growth metrics, especially in the non-irrigated region. The plant failed to get an ideal outcome when the quantity of N treatment was below 160 kg/ha. When using fertilizers that include active nitrogen agents, it is crucial to consider environmental factors, including the availability of moisture and the presence of decomposition bacteria. This is because several biotic and abiotic variables may impact the decomposition of organic matter. Therefore, a higher quantity of organic matter should be used in contrast to synthetic sources to optimize the release and availability of nitrogen to the plant roots.

5.2 Recommendations

I. Pre-Sowing Seed Priming

This study recommends priming wheat seeds with gibberellic and salicylic acid to improve plants' resistance to drought-induced abiotic stress. It also recommends using an irrigation regime of 20 mm every 6 days during the stem elongation stages (Feekes 6 to Feekes 10) and every 3 days throughout the grain filling. Moreover, it advocates cultivating contemporary varieties such as Nemere and Felleg instead of traditional local varieties like Alföld due to their capacity to endure drought stress. The priming strategy described here stimulates important physiological mechanisms that assist plants in coping with water shortages. This observation is consistent with the research conducted by JANDA et al. (2014), who observed that salicylic acid has a role in preserving cell turgor and stabilizing membranes under drought situations. In addition, Zhang et al. (2010) documented that gibberellic acid stimulates root development and improves the absorption of nutrients, which are crucial for supporting growth in times of water scarcity.

II. Laboratory Germination Experiments

This study recommends: (A) conducting maize and wheat seed germination and seedling growth experiments at 20 °C, (B) applying the water amount as a percentage of the TKW for optimization of the water amount suitability, (C) using dry weight as a better indicator of seedlings growth and development, and (D) using a density of no more than six seeds for maize and 15 for wheat per Petri dish since there is no significance of using a higher number of seeds. (E) Seed priming technique presents a better solution for fungal growth inhabitation in laboratory experiments.

III. Effective Microorganisms Experiment

This study recommends the use of irrigation techniques, along with in-crop EM technique and nitrogen, to enhance the crop's capacity to withstand stress situations, particularly drought. It also recommends that applying EM twice at F3 and F10 has a very advantageous impact on significantly improving the yield quantity and quality along nitrogen at a rate of 160-200 kg per hectare, leading to a considerable rise in all vegetative and yield metrics. This recommendation is in line with the litriture, for instance, Hussain et al. (2019) found that integrating EM with N and proper irrigation remarkably enhanced crop abiotic stress tolerance, leading to better yields amount and improved quality.

IV. In-Crop N-Splitting-Timing Experiment

This study recommends the management strategy of N-splitting and N-timing. A total of 160 kg/ha split evenly at 53.33 kg/ha to be applied at the growth stages of Feekes 3, Feekes 6, and Feekes10 to face the abiotic stress of drought and heat and improve the grain production and flour quality. This is consistent with the literature. For instance, Fageria and Baligar (2005) directed that nitrogen splitting across key growth stages improves NUE, ending to enhanced grain quantity and quality, literately under drought and height temperature abiotic stress. This experiment also recommends, in the Hungarian environment, irrigation of 20 mm weekly sataring from Feeks 6 during the dry period, typically during the booting, shooting, and grain-filling phases when there is a lack of precipitation. It also recommends cultivating modern drought-resistant wheat varieties, such as Nemere.

V. Nitrogen Doses- Wheat Quality- Abiotic-Stresses Experiment

Under abiotic stressors of drought and heat, this research recommends applying moderate N at 80 to less than 120 kg/ha at a later stage of the crop life cycle (Heading and grain filling stages), which may enhance grain quality, namely protein and gluten levels. Nevertheless, applying a high rate of nitrogen (120 kg/ha and above) exacerbates abiotic stressors, particularly drought stress, on wheat plants, ultimately leading to a detrimental effect on the yield. The recommendation is in line with other a study when applying N at later wheat growth stages (heading and grain-filling) by Millar et al. (2011), who demonstrate that late N fertilization can have a mixed impact under abiotic stress, it enhances quality parameters but also raises the abiotic stress vulnerability if over-applied.

VI. Maize Field Experiment

To face the abiotic stress of drought and heat, this study recommends (A) applying irrigation of no less than 20 mm weekly starting from growth stage V6to attain optimal crop production and mitigate the negative impacts of drought-induced stress. (B) applying 160 kg/ha of NH_4NO_3 and 240 kg/ha of organic matter is recommended for maize production in a Hungarian environment. (C) On-crop EM application is recommended for early growth stages at a concentration of 1:100 EM solution to water when the soil temperature is around 17 Celsius in the early morning. These recommendations are consistence with the literature of irrigation regime by Olesen et al. (2011), EM application by Higa and Parr (1994), N rates and sources by Fageria et al. (2010) and Liebig et al., (2004).

7 NEW SCIENTIFIC RESULTS

I. An integrated agricultural approach has been developed for better crop adaptation: (A) priming wheat seeds with salicylic acid or gibberellic acid before planting; (B) using an irrigation regime of 20mm water (every minimum 6 to maximum 9 days) during the wheat growth stages (Feekes 6 to Feekes 10); and (C) growing modern wheat varieties, which are better handling abiotic stresses than old ones. This is how to be used in practice as a recommendation.

II. A comprehensive scientific methodology for conducting laboratory experiments specifically tailored to maize and wheat has been developed. The optimization is to conduct maize and wheat seed germination and seedling growth experiments at 20 °C, applying the water amount as a percentage of the TKW, using dry weight as a better indicator of seedlings growth and development, using a density of no more than six seeds for maize and 15 for wheat per Petri dish, and using seed priming technique presents a better solution for fungal growth inhabitation in laboratory experiments. This is how to be used in practice as a recommendation.

III. The application of effective microorganisms has the potential to enhance the resilience of wheat plants under challenging environmental conditions, hence leading to improvements in both the amount and quality of output.

IV. Timing of In-crop effective microorganisms has been determined. They must be applied twice at F3 and F10 since a single application at F3 presents no effect and the best time is F10. EM, along with N, produces robust and resilient plants capable of enduring abiotic stressors and producing under drought. This is how to be used in practice as a recommendation.

V. Management strategy of nitrogen splitting and timing throughout the growth stages of Feekes3, Feekes 6, and Feekes10 is an effective technique to mitigate the abiotic stress caused by drought and heat, while enhancing grain output and improving flour quality. This is how to be used in practice as a recommendation.

VI. In Hungary, for wheat production, in an extreme year of drought and heat stress, a high N dosage of 120 kg/ha and more exacerbation of abiotic stressors because the utilization of N needed extra water, and under these conditions of water scarcity, its high rate increases the negative impact. Moderate to low (around 80 kg/ha) application in the later growth stage may enhance the flour quality. This is how to be used in practice as a recommendation.

VII. Site specific N supply and microbial applications have been identified for wheat (*Triticum* aestivum L.) and maize (*Zea mays* L.) crop varieties regarding the improvement of resistance to abiotic stresses like water scarcity. Optimum dosage have been determined concerning yield quality and quantity of both crop species. This is how to be used in practice as a recommendation.

LIST OF THE PUBLICATIONS RELATED TO THE TOPIC OF THE DISSERTATION

- Khaeim, H.; Kende, Z.; Jolánkai, M.; Kovács, G.P.; Gyuricza, C.; Tarnawa, Á. Impact of Temperature and Water on Seed Germination and Seedling Growth of Maize (*Zea mays* L.). Agronomy **2022**, 12, 397. https://doi.org/10.3390/agronomy12020397
- Khaeim, H.; Kende, Z.; Balla, I.; Gyuricza, C.; Eser, A.; Tarnawa, Á. The Effect of Temperature and Water Stresses on Seed Germination and Seedling Growth of Wheat (*Triticum aestivum* L.). Sustainability **2022**, 14, 3887. https://doi.org/10.3390/su14073887

LIST OF THE PUBLICATIONS NOT RELATED TO THE TOPIC OF THE DISSERTATION

- Tarnawa, Á.; Kende, Z.; Sghaier, A.H.; Kovács, G.P.; Gyuricza, C.; Khaeim, H. Effect of Abiotic Stresses from Drought, Temperature, and Density on Germination and Seedling Growth of Barley (*Hordeum vulgare* L.). Plants **2023**, 12, 1792. https://doi.org/10.3390/plants12091792
- Haj Sghaier, A.; Khaeim, H.; Tarnawa, Á.; Kovács, G.P.; Gyuricza, C.; Kende, Z. Germination and Seedling Development Responses of Sunflower (*Helianthus annuus* L.) Seeds to Temperature and Different Levels of Water Availability. Agriculture **2023**, 13, 608. https://doi.org/10.3390/agriculture13030608
- Haj Sghaier, A.; Tarnawa, Á.; Khaeim, H.; Kovács, G.P.; Gyuricza, C.; Kende, Z. The Effects of Temperature and Water on the Seed Germination and Seedling Development of Rapeseed (Brassica napus L.). Plants 2022, 11, 2819. https://doi.org/10.3390/plants11212819
- Omar, S., Abd Ghani, R., Khaeim, H., Sghaier, A.H., & Jolánkai, M. The effect of nitrogen fertilisation on yield and quality of maize (*Zea mays* L.). Acta Alimentaria **2022**, 51(2), 249-258. https://doi.org/10.1556/066.2022.00022

LIST OF THE CONDUCTED CONFERENCE PRESENTATIONS

- Hussein Khaeim - Gábor Milics - Ákos Tarnawa, **2023**: The responses of wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) to different abiotic stresses: germination and seedling growth. Oral presented in Youth Science Forum, 8 June 2023, Keszthely, Hungary.
- Boglárka Bozóki , Hussein Khaeim , Gergő Péter Kovács , Csaba Gyuricza. Assessment of seed germination and morphological characteristics of two chickpea (Cicer arietinum L.) cultivars under temperature stress. In: Molnár, Dániel; Molnár, Dóra (ed.) XXVI. Spring Wind Conference 2023 - Study volume II. Budapest, Hungary : National Association of Doctoral Students (DOSZ) (2023) 494 p. pp. 92-97. , 6 p.m.
- Boglárka Bozóki , Khaeim Hussein , Lili Uzner , Péter Kovács Gergő , Csaba Gyuricza. Assessment of Seed Germination and Morphological Characteristics of Two Chickpea (Cicer Arietinum L.) Cultivars Under Temperature Stress. In: Hajdú, Péter (ed.) XXVI. Spring Wind Conference 2023: Abstract volume. Budapest, Hungary : National Association of Doctoral Students (DOSZ) (2023) 513 p. pp. 40-40. , 1 p.

LIST OF THE CONDUCTED YMPOSIUM PRESENTATIONS

- Boglárka Bozóki , Khaeim Hussein , Lili Uzner , Péter Kovács Gergő , Csaba Gyuricza. Effects of high temperature stress on germination and morphological characteristics of two peanut (Arachis hypogaea L.) varieties In: Hajdú, Péter (ed.) II. Symposium of Hungarian PhD Students in Agricultural Sciences 2024, Budapest, Hungary : National Association of Doctoral Students (DOSZ) (2024) pp. 54-54. , 1 p.