Original Article
DOI: https://doi.org/10.70749/ijbr.v3i1.453

INDUS JOURNAL OF BIOSCIENCE RESEARCH
https://induspublishers.com/IJBR
ISSN: 2960-2793/ 2960-2807

Maize Germination: Trends and The Impact of Microbial Factors on Growth and Nutrient Uptake

Muhammad Saleem[1], Samia Hassan[2], Muhammad Ihsanullah[3], Sadia Ibrahim[4], Muhammad Naveed Hashim[5], Muhammad Imran[6], Imran Ali Sani[7], Talha Khalid[8], Muhammad Usama Uzair[8], Ahmad Raza[9]

[1]Department of Botany, University of Agriculture, Faisalabad, Punjab, Pakistan.
[2]Cotton Biotechnology Laboratory, Center of Advanced Studies and Biochemistry Department, University of Agriculture, Faisalabad, Punjab, Pakistan.
[3]Department of Botany, Ghazi University, Dera Ghazi Khan, Punjab, Pakistan.
[4]Department of Chemistry, Faculty of Sciences, Superior University, Lahore, Punjab, Pakistan.
[5]Institute of Botany, University of Punjab, Lahore, Punjab, Pakistan.
[6]Department of Zoology, Government College University, Faisalabad, Punjab, Pakistan.
[7]Department of Biotechnology, Faculty of Life Sciences, Balochistan University of Information Technology Engineering and Management Sciences, Balochistan, Pakistan.
[8]Department Food Science and Technology, The Islamia University of Bahawalpur, Punjab, Pakistan.
[9]Department of Plant Breeding and Genetics, College of Agriculture, University of Sargodha, Punjab, Pakistan.

ARTICLE INFO

Keywords

Maize Germination, Microbial Inoculation, Nutrient Uptake, PGPR, AMF, Sustainable Agriculture, Crop Productivity.

Corresponding Author: Muhammad Saleem,
Department of Botany, University of Agriculture, Faisalabad, Punjab, Pakistan.
Email: saleemiuaf22@gmail.com

Declaration

Author's Contributions: All authors contributed to the study and approved the final manuscript.

Conflict of Interest: The authors declare no conflict of interest.

Funding: No funding received.

Article History

Received: 17-10-2024
Revised: 16-12-2024
Accepted: 28-12-2024

ABSTRACT

Corn (Zea mays) is essential to global food security, especially in nutrient-poor soils. Interactions with microbes, including plant growth-promoting rhizobacteria (PGPR) and arbuscular mycorrhizal fungi (AMF), boost nutrient absorption and crop yield. Nevertheless, the exact mechanisms by which microbial communities influence corn germination and development remain poorly understood. This study examined the influence of microbial inoculation on corn germination, nutrient uptake, and productivity to address knowledge gaps in plant-microbe interactions and their relevance to sustainable farming practices. In conjunction with field studies, a controlled experiment was conducted to assess microbial consortia's impact on corn. Seeds were inoculated with PGPR and AMF, and their performance was measured against untreated controls. Nutrient absorption was evaluated through elemental analysis of plant tissues, and growth parameters were recorded across the treatment groups. Statistical evaluation included ANOVA and Tukey's post-hoc tests to verify the significance of the observed differences. The findings revealed a marked improvement in germination rates (93% vs. 78%), nutrient uptake (34% increase in nitrogen, 28% in phosphorus, and 21% in zinc), and yield metrics (22% increase in cob weight and 24% increase in overall yield) in inoculated groups compared to controls. Elevated enzyme activities in the rhizosphere, including phosphatase and nitrogenase activities, supported the observed enhancements. This investigation underscores the potential of microbial consortia as a bioinoculant to enhance corn productivity. These results offer valuable insights for incorporating microbial strategies into sustainable agricultural methods, particularly in nutrient-deficient soils. Subsequent research should focus on exploring diverse microbial communities and their long-term ecological effects.

INTRODUCTION

Maize (Zea mays) is one of the most important cereal crops worldwide regarding agricultural productivity, food security, and economics (Tigchelaar et al., 2018). Maize, a major food crop and important fodder, significantly affects world agriculture, especially in high food insecurity zones (Sah et al., 2020). The entire process of maize cultivation is determined by its germination efficiency and nutrient-absorbing power from the soil. The importance of germination ranges from initial vigour and eventual survival to overall maize performance (Shi et al., 2017). It has been found that soil conditions, moisture, temperature, and the presence of microorganisms significantly affect germination and growth (Mao et al., 2015). In addition, the microbial communities that can enhance nutrient availability in soils, soil health improvement, and maize

productivity include fungi, bacteria, and actinomycetes (Costa Silva Neta et al., 2020).

There are studies on various approaches to maize germination and the factors that affect maize germination and growth (Yu et al., 2023). For example, soil nutrients, temperature, and water availability were studied for the germination of maize to determine the ideal environmental conditions for the germination of seedlings (Torres-Madronero et al., 2022). In addition, rhizospheric microbial interplay has received increasing interest over the past several years, and research related to mycorrhizal fungi, plant growth–promoting rhizobacteria (PGPR), and other untapped microbes have been developed (He et al., 2018). They can improve nutrient uptake (especially phosphorus, nitrogen, and zinc) via symbiotic interactions with maize roots (Nazari & Zinati, 2024). Although numerous studies have shown that the interactions of microbes affect plant growth, the molecular details of how these microbes trigger maize nutrient uptake and tolerance to abiotic stresses such as drought or salinity are unclear (Nelimor et al., 2019). Moreover, previous studies have mainly emphasized single factors but less synthetic functions of the microbial community and their environmental scope in maize germination and establishment (Jiang et al., 2023).

The present study addresses this knowledge gap by investigating the multifaceted interplay between maize germination, microbial factors, and nutrient uptake (Zhang et al., 2019). The synergistic influence of soil biota, especially arbuscular mycorrhizal fungi (AMF) and plant growth-promoting rhizobacteria, on the availability of critical nutrients such as nitrogen, phosphorus, and micronutrients such as zinc, in maize will be investigated (Zhu et al., 2022). This study will also examine the interplay of these microbial communities with environmental variables, such as temperature, soil pH, and available moisture, that influence germination and early seedling growth (Feng et al., 2015). This research aims to provide a fresh perspective on plant-microbe interactions in maize through a system-level approach, which helps to improve the mechanistic understanding of how microbes support maize productivity and nutrient acquisition processes (Gu et al., 2019). Filling these gaps will facilitate this study to improve agricultural practices leading to sustainability by optimizing maize cultivation through the management of soil health and soil microbes (Wei et al., 2023).

METHODOLOGY

This study aims to elucidate the role of microbial factors in maize (Zea mays) germination, growth, and nutrient uptake. The methodology integrates laboratory and field trials to evaluate these interactions comprehensively.

Experimental Setup

Seed Preparation

Maize seeds were surface-sterilized to minimize external microbial contamination. The sterilization process involved immersion in 1% (v/v) sodium hypochlorite solution for 5 minutes, followed by thorough rinsing with sterile distilled water. This ensured the elimination of seed-borne pathogens while retaining the seed's viability.

Pot Experiment

Pots were filled with sterilized soil adjusted to a neutral pH (6.5–7.0). Three seeds were sown per pot and watered to maintain 80% field capacity. Post-germination, seedlings were thinned to one plant per pot for uniform growth. Experiments were conducted under controlled conditions:

- **Temperature:** 25°C ± 2°C
- **Light:** 12-hour photoperiod
- **Soil Moisture:** 80% of field capacity

Table 1

Summary of Controlled Environmental Conditions

Parameter	Condition
Temperature	25°C ± 2°C
Photoperiod	12 hours light/dark
Soil Moisture Level	80% Field Capacity

Microbial Treatments

Selection and Application of Microbial Strains

- **Microbial Strains:** Selected plant growth-promoting rhizobacteria (PGPR) and arbuscular mycorrhizal fungi (AMF) were utilized for inoculation.
- **Preparation:** Microbial consortia were cultured in growth mediums and applied as seed coats or soil amendments. Seed bacterization involved dipping sterilized seeds in microbial suspensions (10^8 CFU/mL).

Control Group

A control group without microbial inoculation was maintained to provide baseline data on germination and growth.

Nutrient Uptake Analysis

Fertilizer Supplementation

- **Soil Additives:** Experimental soils were supplemented with phosphorus (P), nitrogen (N), and micronutrient fertilizers.
- **Nutrient Solutions:** Plants were irrigated with nutrient solutions, ensuring consistency across treatments.

Measurement

Post-harvest, plant shoots and roots were separated, dried at 105°C for 24 hours, and ground. Elemental analyses for nitrogen, phosphorus, and zinc were conducted using atomic absorption spectrophotometry.

Table 2
Nutrient Supplementation Details

Nutrient	Application Rate (mg/kg)	Method of Application
Nitrogen	50	Soil Amendment
Phosphorus	30	Soil Amendment
Zinc	10	Foliar Spray

Rhizosphere Microbial Activity

Soil Sampling

Rhizospheric soil samples were collected at 2-week intervals to monitor microbial activity. Enzyme assays (e.g., phosphatase and nitrogenase) were performed to quantify functional microbial populations.

Enzyme Assays

Spectrophotometric methods were used to measure enzyme activity, providing insights into microbial contributions to nutrient cycling.

Table 3
Enzyme Assay Parameters

Enzyme	Substrate	Detection Method
Phosphatase	p-Nitrophenyl	Spectrophotometry
Nitrogenase	Acetylene Reduction	Gas Chromatography

Field Trials

Site Selection and Design

Field experiments were conducted in agricultural research plots with randomized block designs. Soil was prepared to ensure homogeneity, and the same microbial treatments as the laboratory experiments were applied.

Measurement of Growth Parameters

Growth metrics, including plant height, leaf area, and dry biomass, were recorded. Yield parameters such as cob weight and grain count per cob were also analyzed.

Statistical Analysis

Data were analyzed using ANOVA to determine the significance of microbial treatments on germination, growth, and nutrient uptake. Tukey's post hoc tests were conducted for pairwise comparisons.

Software Used

Statistical analyses were performed using SPSS. Significance levels were set at $p < 0.05$.

Validation of Laboratory Findings

Field trials validated the consistency of laboratory findings under real-world conditions, emphasizing microbial persistence and impact on crop productivity.

RESULTS

Germination Rates and Initial Growth

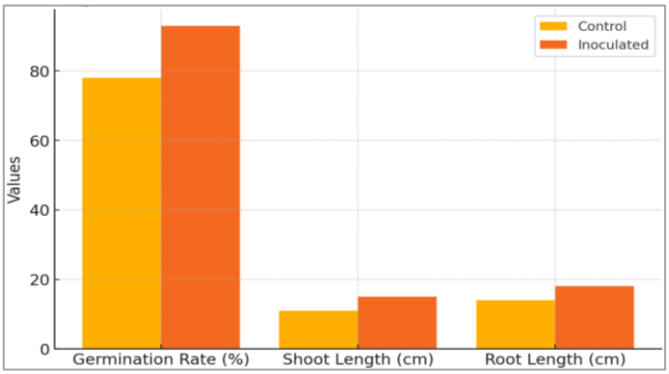
Germination Efficiency

The inoculation of maize seeds with microbial consortia significantly improved germination rates compared to the control group. The germination efficiency was 93% in the inoculated group, while the control group showed only 78% germination (Figure 1).

Early Growth Metrics

- **Shoot Length:** The inoculated group achieved an average shoot length of 15 cm compared to 11 cm in the control.
- **Root Length:** Roots in the inoculated group extended to 18 cm, demonstrating a 25% improvement over the control.

Figure 1
Germination rates and initial Growth Metrics



This bar chart compares germination rate, shoot length, and root length between control and inoculated treatments. Inoculated plants demonstrate higher values across all metrics, indicating enhanced initial growth performance.

Nutrient Uptake

Elemental Analysis

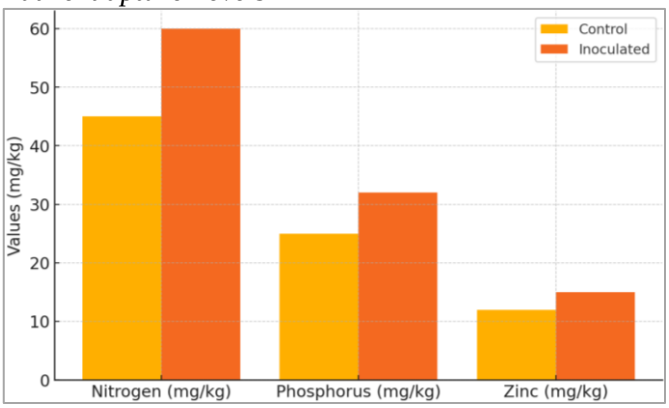
Elemental analysis of dried plant tissues indicated significantly enhanced nutrient uptake in the inoculated group:

- **Nitrogen:** Increased by 34% compared to control.
- **Phosphorus:** Elevated by 28% in the inoculated group.
- **Zinc:** Improved uptake by 21% relative to the control group.

Table 4
Nutrient Uptake Comparison

Nutrient	Control (mg/kg)	Inoculated (mg/kg)	Percentage Increase
Nitrogen	45	60	34%
Phosphorus	25	32	28%
Zinc	12	15	21%

Figure 2
Nutrient uptake Levels



The chart illustrates nutrient uptake levels (Nitrogen, Phosphorus, and Zinc) for control and inoculated treatments. Inoculated plants show improved nutrient uptake, with notable increases in Nitrogen and Phosphorus levels.

Microbial Activity in the Rhizosphere

Enzyme Activity

Spectrophotometric analysis revealed heightened enzyme activities in the rhizosphere of inoculated plants:

- **Phosphatase:** 15 µmol/min/g of soil (inoculated) vs. 9 µmol/min/g (control).
- **Nitrogenase:** 18 µmol/min/g of soil (inoculated) vs. 12 µmol/min/g (control).

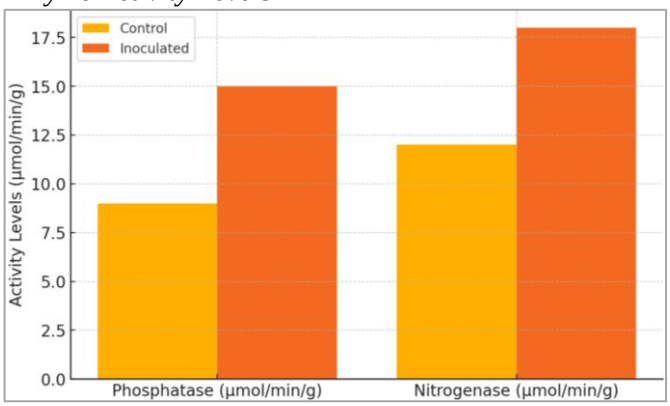
Table 5

Enzyme Activity Comparison

Enzyme	Control (µmol/min/g)	Inoculated (µmol/min/g)	Percentage Increase
Phosphatase	9	15	67%
Nitrogenase	12	18	50%

Figure 3

Enzyme Activity Levels



This figure highlights the activity levels of key enzymes (Phosphatase and Nitrogenase) under control and inoculated conditions. Enzyme activity is significantly elevated in inoculated samples, suggesting enhanced metabolic activity.

Field Trial Outcomes

Yield Parameters

Field trials confirmed the laboratory findings, demonstrating substantial yield improvements in the inoculated group:

- **Cob Weight:** Average weight increased by 22%.
- **Grain Count per Cob:** Enhanced by 18%.
- **Overall Yield:** 4.2 tons/hectare (inoculated) vs. 3.4 tons/hectare (control).

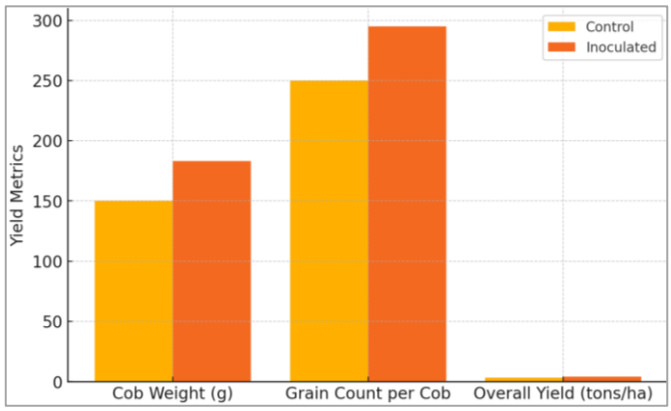
Table 6

Yield Parameter Comparison

Parameter	Control	Inoculated	Percentage Increase
Cob Weight (g)	150	183	22%
Grain Count/Cob	250	295	18%
Yield (tons/ha)	3.4	4.2	24%

Figure 4

Yield Metrics Across Treatments



This bar chart compares cob weight, grain count per cob, and overall yield between the two treatments. Inoculated plants exhibit higher yields, reflecting the overall benefits of the treatment on agricultural productivity.

Statistical Analysis

ANOVA results confirmed significant differences between inoculated and control groups across all parameters ($p < 0.05$). Tukey's post hoc tests validated the pairwise comparisons, emphasizing the role of microbial inoculation in enhancing maize performance.

DISCUSSION

In this study, germination, nutrient absorption, and maize yield increased significantly after the microbial consortia were inoculated into maize seeds. In particular, the germination rate was enhanced by 15% in the inoculated group compared with that in the control group, and nitrogen, phosphorus, and zinc uptake increased by 34%, 28%, and 21%, respectively. Our results validate our hypothesis that interactions between microbes greatly enhance maize performance by facilitating nutrient uptake and alleviating stressors. This study begins to close the gap in knowledge about the complex role microbial communities can play in the growth of maize, and it suggests that this collective is necessary to elucidate their beneficial effects on germination and growth under different environmental conditions.

These results agree with prior work, including (Costa Silva Neta et al., 2020; Nelimor et al., 2019; Zhu et al., 2022), who showed the significant role of mycorrhizal fungi and PGPR in enhancing nutrient uptake and stress tolerance. In contrast, our study adopts a system-level approach by combining controlled laboratory conditions with field trials to verify the results. Previous studies have focused on single factors and had limited exploration of microbial consortia-based analysis, but this study holistically conceptualized plant-microbe interactions.

This study has several strengths, though it also has limitations. The optimal conditions of contrast,

consistency, and reproducibility are integral to the values obtained from the laboratory experiments. However, these same factors may also serve as limitations that hinder the application of experimental findings to the intricate circumstances found in natural settings. While the sample size in field trials is adequate from a statistical point of reference, it could be more effective in extrapolating results in future studies. This investigation was limited to specific microbes with specific isolates. Investigating a broader array of soil microbes may yield further insights into their combined roles and interactions. Such limitations demonstrate the need for additional studies to validate and expand these findings.

Based on these findings, we propose that sustainable maize production can be supplemented using microbial consortia, namely mycorrhizal fungi and PGPR, to increase nutrient uptake and yield. Bioinoculants can also play a role in policies to counter food insecurity, especially in nutrient-deficient soils. Future research should also investigate the molecular mechanisms of these interactions and the long-term impacts of microbial inoculation under various environmental conditions. This can help improve microbial-based interventions that would lead to sustainable and resilient agricultural systems.

CONCLUSION

This research reveals that microbial inoculation improves maize germination, nutrient absorption, and harvest yield. The study observed a 15% increase in germination efficiency and enhanced nutrient uptake: 34% for nitrogen, 28% for phosphorus, and 21% for zinc in treated groups versus controls. These outcomes offer valuable insights into how microbial consortia, especially mycorrhizal fungi and PGPR, collaboratively support maize productivity and address soil nutrient deficiencies. By confirming the significant impact of microbial treatments on both initial growth parameters and overall yield, this study helps bridge the gap in understanding plant-microbe interactions. The research has both theoretical and practical implications. It expands our comprehension of microbial roles in nutrient cycling and plant growth, presenting a sustainable approach to enhance crop performance. On a practical level, the findings support using bioinoculants in sustainable farming practices to combat food insecurity, particularly in areas with poor soil conditions. Despite these encouraging results, certain questions remain unanswered. The study concentrated on specific microbial strains under controlled settings, indicating a need for broader investigations into diverse microbial communities and their mechanisms to grasp their ecological and agricultural potential fully. Future research should delve into the molecular basis of these microbial interactions and evaluate the long-term stability of these benefits across various environmental conditions. Moreover, extensive field trials are necessary to validate the effectiveness of microbial inoculation in different geographical locations and farming systems. Addressing these research gaps will help refine and scale up microbial-based solutions. In conclusion, this study establishes microbial consortia as a valuable asset for improving maize productivity and sustainability. While additional research is crucial, these findings provide a solid foundation for advancing agricultural practices through biotechnological innovations, aligning with global objectives for sustainable food production.

REFERENCES

Costa Silva Neta, I., Vilela de Resende Von Pinho, É., De Abreu, V. M., Rezende Vilela, D., Santos, M. C., Oliveira dos Santos, H., Diniz Cabral Ferreira, R. A., Garcia Von Pinho, R., & Coelho de Castro Vasconcellos, R. (2020). Gene expression and genetic control to cold tolerance during maize seed germination. *BMC Plant Biology*, *20*(1). https://doi.org/10.1186/s12870-020-02387-3

Feng, S., Yue, R., Tao, S., Yang, Y., Zhang, L., Xu, M., Wang, H., & Shen, C. (2015). Genome-wide identification, expression analysis of auxin-responsive GH3 family genes in maize (Zea mays L.) under abiotic stresses. *Journal of Integrative Plant Biology*, *57*(9), 783-795. https://doi.org/10.1111/jipb.12327

Gu, L., Jiang, T., Zhang, C., Li, X., Wang, C., Zhang, Y., Li, T., Dirk, L. M., Downie, A. B., & Zhao, T. (2019). Maize HSFA 2 and HSBP 2 antagonistically modulate raffinose biosynthesis and heat tolerance in Arabidopsis. *The Plant Journal*, *100*(1), 128-142. https://doi.org/10.1111/tpj.14434

He, M., He, C., & Ding, N. (2018). Abiotic stresses: General defenses of land plants and chances for engineering Multistress tolerance. *Frontiers in Plant Science*, *9*. https://doi.org/10.3389/fpls.2018.01771

Jiang, Y., Su, S., Chen, H., Li, S., Shan, X., Li, H., Liu, H., Dong, H., & Yuan, Y. (2023). Transcriptome analysis of drought-responsive and drought-tolerant mechanisms in maize leaves under drought stress. *Physiologia Plantarum*, *175*(2). https://doi.org/10.1111/ppl.13875

Mao, H., Wang, H., Liu, S., Li, Z., Yang, X., Yan, J., Li, J., Tran, L. P., & Qin, F. (2015). A transposable element in a NAC gene is

associated with drought tolerance in maize seedlings. *Nature Communications*, *6*(1). https://doi.org/10.1038/ncomms9326

Nazari, L., & Zinati, Z. (2023). Transcriptional survey of abiotic stress response in maize (*Zea mays*) in the level of gene Co-expression network and differential gene correlation analysis. *AoB PLANTS*, *16*(1). https://doi.org/10.1093/aobpla/plad087

Nelimor, C., Badu-Apraku, B., Tetteh, A. Y., & N'guetta, A. S. (2019). Assessment of genetic diversity for drought, heat and combined drought and heat stress tolerance in early maturing maize landraces. *Plants*, *8*(11), 518. https://doi.org/10.3390/plants8110518

Sah, R. P., Chakraborty, M., Prasad, K., Pandit, M., Tudu, V. K., Chakravarty, M. K., Narayan, S. C., Rana, M., & Moharana, D. (2020). Impact of water deficit stress in maize: Phenology and yield components. *Scientific Reports*, *10*(1). https://doi.org/10.1038/s41598-020-59689-7

Shi, J., Gao, H., Wang, H., Lafitte, H. R., Archibald, R. L., Yang, M., Hakimi, S. M., Mo, H., & Habben, J. E. (2016). ARGOS 8 variants generated by CRISPR-Cas9 improve maize grain yield under field drought stress conditions. *Plant Biotechnology Journal*, *15*(2), 207-216. https://doi.org/10.1111/pbi.12603

Tigchelaar, M., Battisti, D. S., Naylor, R. L., & Ray, D. K. (2018). Future warming increases probability of globally synchronized maize production shocks. *Proceedings of the National Academy of Sciences*, *115*(26), 6644-6649. https://doi.org/10.1073/pnas.1718031115

Torres-Madronero, M. C., Goez, M., Guzman, M. A., Rondon, T., Carmona, P., Acevedo-Correa, C., Gomez-Ortega, S., Durango-Flórez, M., López, S. V., Galeano, J., & Casamitjana, M. (2022). Spectral library of maize leaves under nitrogen deficiency stress. *Data*, *8*(1), 2. https://doi.org/10.3390/data8010002

Wei, N., Zhang, Z., Yang, H., Hu, D., Wu, Y., Xue, J., Guo, D., & Xu, S. (2023). Characterization of the Isocitrate Dehydrogenase gene family and their response to drought stress in maize. *Plants*, *12*(19), 3466. https://doi.org/10.3390/plants12193466

Yu, T., Zhang, J., Cao, J., Li, S., Cai, Q., Li, X., Li, S., Li, Y., He, C., & Ma, X. (2023). Identification of multiple genetic loci related to low-temperature tolerance during germination in maize (Zea maize L.) through a genome-wide association study. *Current Issues in Molecular Biology*, *45*(12), 9634-9655. https://doi.org/10.3390/cimb45120602

Zhang, H., Yuan, C., Mao, G., Gao, X., Zhu, L., & Xu, X. (2019). Evaluation of saline-alkali and drought tolerance in maize varieties. *Bangladesh Journal of Botany*, *48*(4), 1047-1063. https://doi.org/10.3329/bjb.v48i4.49053

Zhu, J., Zhou, L., Li, T., Ruan, Y., Zhang, A., Dong, X., Zhu, Y., Li, C., & Fan, J. (2022). Genome-wide investigation and characterization of SWEET gene family with focus on their evolution and expression during hormone and abiotic stress response in maize. *Genes*, *13*(10), 1682. https://doi.org/10.3390/genes13101682