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Integrated Effect of Seed Priming and Inoculation on Growth and Yield of Maize (*Zea Mays* L.)

Majid Hussain Dayo
Department of Agronomy, Sindh Agriculture University Tandojam, Pakistan.

Pir Ahmed Naqi Shah
Department of Agronomy, Sindh Agriculture University Tandojam, Pakistan.

Asif Ali Kaleri
Department of Agronomy, Sindh Agriculture University Tandojam, Pakistan.

Danish Manzoor (Corresponding Author)
Department of Agronomy, Sindh Agriculture University Tandojam, Pakistan.
Email: danishmanzoor2707@gmail.com

Maira Raqeeb Tunio
Department of Horticulture, Sindh Agriculture University Tandojam, Pakistan.

Abdul Jabbar
Department of Agronomy, Sindh Agriculture University Tandojam, Pakistan.

Sarang Ali Bhand
Department of Plant Breeding and Genetics, Sindh Agriculture University Tandojam, Pakistan.

Dad Jan
Research Officer Directorate of Agriculture Research Wayaro Farm Uthal, Lasbela, Balochistan, Pakistan.

Niaz Ahmad
Directorate of Agriculture Research Dates Turbat, Balochistan, Pakistan.

Arslan Nazeer Channa
Department of Plant Breeding and Genetics, Sindh Agriculture University Tandojam, Pakistan.

Urooj Rehmani
Department of Agronomy, The University of Agriculture Peshawar, Pakistan.

Abstract
Integrating effective seed treatments is pivotal for enhancing maize crop performance. This study explores the combined impact of seed inoculation with PGPR (Biozote Max) and seed priming with canal water (6hr) on the growth and yield of maize. Field experiments were conducted at the student's experimental farm, department of Agronomy, Sindh Agriculture University Tandojam, utilizing a randomized complete block design in three replications. The

treatments included untreated (Control), seed Inoculation with (PGPR), seed priming with canal water (6hr) and a combined seed priming with subsequent PGPR inoculation. Key growth parameters, including plant population, plant height, cobs plant^{-1}, stem girth, biological yield, seed index and grain yield, were assessed. Statistical analyses revealed significant ($P<0.05$) impacts of seed treatments on maize crop growth and yield. Results demonstrated that the integrated treatment, involving seed priming followed by PGPR inoculation, significantly outperformed other treatments in terms of maximum plant population 16.77, plant height 226.21 cm, cobs plant^{-1} 2.11, stem girth 3.51cm, biological yield 8095 kg ha^{-1}, seed index, 297.74, grain yield 4.47 plot^{-1} and grain yield 3802 kg ha^{-1}. Seed Inoculation with PGPR in-oculum (Biozote Max) ranked 2nd with plant population 14.76, plant height 212.88 cm, cobs plant^{-1}1.44, stem girth 2.70 cm, biological yield 7000 kg ha^{-1} seed index 293.57, grain yield 4.12 plot^{-1} and grain yield 3545.7 kg ha^{-1}. However, minimum performance was observed in Untreated (Control) with lowest plant population 9.05, plant height 166.72 cm, cobs plant^{-1} 1.00, stem girth 2.37 cm, biological yield 5582 kg ha^{-1}, seed index 243.70, grain yield 3.07 plot^{-1} and grain yield 3039.7 kg ha^{-1}. These findings provide valuable insights for optimizing seed treatment strategies in maize cultivation, with implications for enhancing crop productivity and sustainability.

Key words: Maize, Growth, yield, PGPR.

Introduction

Maize (*Zea mays* L.) is a crucial cereal crop globally, serving as a primary source of both food and feed in many countries, particularly in tropical and sub-tropical regions (Rajput et al., 2023). Maize is the third important cereal crop of Pakistan after wheat and rice. It contributes 3.4 percent to the value added in agriculture and 0.6 percent to GDP (Azam et al., 2017). Rich in protein, maize's storage proteins mainly comprise prolamines, making it a significant staple food alongside its versatile applications in producing oil, gluten, starch, and high fructose corn syrup. Furthermore, byproducts like corn steep liquor find applications in the biochemical industry and research as culture media for various microorganisms. However, the excessive use of nitrogen fertilizers, particularly in new maize cultivars, has led to environmental concerns due to increased pollution and eutrophication (Wani et al., 2021). Seed priming, also known as pre-soaking, has become one of the most promising techniques for enhancing both abiotic and biotic stress tolerance, as well as improving crop yield and growth in crop plants (Salam et al., 2022). This approach involves altering the seed vigor and physiological state to enhance seed germination and improve the overall development ability of the plant. Another seed priming technique gaining attention is myco-priming, which involves using fungal biocontrol agents or entomopathogenic fungi to enhance crop growth and improve tolerance against herbivores (Khashaba, 2021). In addition to seed priming and myco-priming, numerous biological products based on beneficial microbes, such as mycorrhizae, Beauveria, Trichoderma, Pseudomonas, Bacillus, and more, are extensively used to promote plant growth and increase crop yield. These beneficial microbes have proven effective in controlling plant diseases and

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pests, making them valuable tools in sustainable agricultural practices (Di Lelio et al., 2021). The combination of seed priming and myco-priming, along with the application of beneficial microbes, holds great potential in revolutionizing modern agriculture. Seed priming with HA also plays a vital role in maintaining a delicate balance between the synthesis and catabolism of abscisic acid (ABA) and gibberellic acid (GA), which are crucial plant hormones. This balance is pivotal in promoting favourable plant growth and enhancing water use efficiency. Additionally, HA has been found to reduce the transpiration rate and improve water use efficiency in plant roots (Rajput et al., 2023). In the rhizosphere, beneficial microorganisms, such as plant growth-promoting rhizobacteria (PGPR), also play a significant role in promoting plant growth and health. These PGPR establish symbiotic relationships with plant roots, facilitating nutrient uptake, enhancing tolerance to stress, and protecting plants from pathogens (Mohanty et al., 2021). The combination of seed priming with HA and the presence of beneficial PGPR in the rhizosphere synergistically contribute to improved plant growth, nutrient acquisition, and overall crop productivity. Seed priming is a controlled hydration and partial germination process that improves seed vigor and uniformity. It has positive effects on maize germination and early seedling growth, promoting faster and more uniform germination (Kaleri et al., 2024). Primed maize seeds show higher germination percentages and faster emergence rates compared to non-primed ones. Seed priming also enhances stress tolerance in maize plants, allowing them to cope better with water-deficient environments. Furthermore, studies have demonstrated that the activities of soil enzymes, including acid phosphatase and dehydrogenase, are positively influenced by the presence of beneficial microorganisms in the rhizosphere. These enzymes play vital roles in nutrient cycling and soil health (Vocciante et al., 2022).

Materials and Methods

The field experiment took place at the Student's Experimental Farm, which is part of the Department of Agronomy at Sindh Agriculture University, Tandojam, during autumn, 2023 to assess the "integrated effect of seed priming and inoculation on growth and yield of maize (*zea mays* L.)" The experiment was designed with randomized complete block design with net plot size 4m x 3m (12m^2). Mechanical implements were used to adopt a good seedbed with suitable land preparation as per recommended practice for maize. Examined treatments T_1 = Untreated (Control), T_2 = Seed Inoculation with PGPR in-oculum (Biozote Max), T_3 = Seed Priming with canal water (6 hours), T_4 = (T_{3+} T_2) at the time of maturity five plant was selected in each experimental plots and the units to measure, Plant populations (m^{-2}), Plant height (cm), Cobs plant^{-1}, Stem grith (cm), Biological yield (kg ha^{-1}), Seed index (1000-grain wt., g), Grain yield (kg plot^{-1}), Grain yield (kg ha^{-1}) were recorded.

Statistical Analysis

The collected data underwent statistical analysis using ANOVA through Statistix-8.1 Computer Software (Statistix, 2006). In cases where it was required, the LSD test was utilized to compare the superiority of treatments.

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Results

Plant population (m^{-2})

The impact of seed treatments on the response of maize plants to management factors, with a particular emphasis on plant population. Various treatments were implemented and their effects on plant population were investigated. The analysis of variance (Appendix-1) revealed a significant ($P<0.05$) influence of different seed treatments on the growth and yield of the maize crop. The results indicated that the plant population at germination stage was (16.777) under the treatment of T_4 = Seed Priming with canal water (6 hours) after the T_3 then in-oculate with PGPR T_2. Followed by (14.767 and 12.293) under T_2 = Seed Inoculation with PGPR in-oculum (Biozote Max) and T_3 = Seed Priming with canal water (6 hours). The plant population at germination of maize crop was further reduced to 9.057 for T_1 = Untreated (Control) respectively.

Plant height (cm)

The impact of seed treatments methods on maize plants reacts to various management factors, with a focus on plant height. The various treatments were applied, and their effects on plant height were examined. The results indicated that the plant height at maturity stage was (226.21) under the treatment of T_4 = Seed Priming with canal water (6 hours) after the T_3 then in-oculate with PGPR T_2. Followed by (212.88 cm) under T_2 = Seed Inoculation with PGPR in-oculum (Biozote Max). The plant height at maturity stage of maize crop was further reduced to (182.73 cm) for T_3 = Seed Priming with canal water (6 hours). The lowest (166.72cm) plant height was measured under T_1 = Untreated (Control) respectively.

Cobs plant $^{-1}$

The impact of seed treatments methods on maize plants reacts to various management factors, with a focus on cobs plant^{-1}. The various treatments were applied, and their effects on cobs plant^{-1} were examined. The results indicated that the cobs plant^{-1} at maturity stage was (2.110) under the treatment of T_4 = Seed Priming with canal water (6 hours) after the T_3 then in-oculate with PGPR T_2. Followed by (1.440) under T_2 = Seed Inoculation with PGPR in-oculum (Biozote Max). The cobs plant^{-1} at maturity stage of maize crop was further reduced to (1.220) for T_3 = Seed Priming with canal water (6 hours). The lowest (1.00) cobs plant^{-1} was measured under T_1 = Untreated (Control) respectively.

Stem girth (cm)

The impact of seed treatments on the response of maize plants to management factors, with a particular emphasis on stem girth. Various treatments were implemented and their effects on stem girth were investigated. The results indicated that the stem girth at maturity stage was (3.51) under the treatment of T_4 = Seed Priming with canal water (6 hours) after the T_3 then in-oculate with PGPR T_2. Followed by (2.70) under T_2 = Seed Inoculation with PGPR in-oculum (Biozote Max). The stem girth at maturity stage of maize crop was further reduced to (2.37) for T_1 = Untreated (Control). The lowest (2.31) stem girth was

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measured under T_3 = Seed Priming with canal water (6 hours) respectively.

Treatments	Plant population (m^{-2})	Plant height (cm)	Cobs plant $^{-1}$	Stem girth (cm)
T_1 = Untreated (Control)	**9.05 d**	**166.72 d**	**1.00 c**	**2.3700 b**
T_2 = Seed Inoculation with PGPR in-oculum (Biozote Max)	**14.76 b**	**212.88 b**	**1.44 b**	**2.7000 b**
T_3 = Seed Priming with canal water (6 hours)	**12.29 c**	**182.73 c**	**1.22 c**	**2.3167 b**
T_4 = Seed Priming with canal water (6 hours) after the T_3 then in-oculate with PGPR T_2.	**16.77 a**	**226.21 a**	**2.11 a**	**3.5167 a**
S.E.±	**0.4443**	**3.6394**	**0.1489**	**0.1836**
LSD	**0.2812**	**5.4036**	**0.5220**	**0.6180**
P value	**0.0000**	**0.0000**	**0.0001**	**0.0225**

Biological yield (kg ha^{-1})

The impact of seed treatments methods on maize crops reacts to various management factors, with a focus on biological yield (kg ha^{-1}) in particular. The various treatments were applied, and their effects on biological yield (kg ha^{-1}) were examined. The results indicated that the biological yield at harvesting time was (8095 kg ha^{-1}) under the treatment of T_4 = Seed Priming with canal water (6 hours) after the T_3 then in-oculate with PGPR T_2. Followed by (7000 kg ha^{-1}) under T_2 = Seed Inoculation with PGPR in-oculum (Biozote Max). The biological yield at harvesting stage of maize crop was further reduced to (6009 kg ha^{-1}) for T_3 = Seed Priming with canal water (6 hours). The lowest (5582.8 kg ha^{-1}) biological yield was measured under T_1 = Untreated (Control) respectively.

Seed index (1000-grain wt., g)

The impact of seed treatments on the response of maize plants to management factors, with a particular emphasis on seed index (1000-grain wt., g). Various treatments were implemented and their effects on seed index were investigated. The results indicated that the seed index at harvesting stage was (297.74) under the treatment of T_4 = Seed Priming with canal water (6 hours) after the T_3 then in-oculate with PGPR T_2. Followed by (293.56) under T_2 = Seed Inoculation with PGPR in-oculum (Biozote Max). The seed index at harvesting stage of maize crop was further reduced to (285.76) for T_3 = Seed Priming with canal water (6 hours). The lowest (243.70) seed index was measured under T_1 = Untreated (Control)

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respectively.

Grain yield (kg plot $^{-1}$)

The impact of seed treatments on the response of maize plants to management factors, with a particular emphasis on grain yield (kg plot $^{-1}$). Various treatments were implemented and their effects on seed index were investigated. The results indicated that the grain yield (kg plot $^{-1}$) at harvesting stage was (4.47) under the treatment of T_4 = Seed Priming with canal water (6 hours) after the T_3 then in-oculate with PGPR T_2. Followed by (4.12) under T_2 = Seed Inoculation with PGPR in-oculum (Biozote Max). The grain yield (kg plot $^{-1}$) at harvesting time of maize crop was further reduced to (3.65) for T_3 = Seed Priming with canal water (6 hours). The lowest (3.07) grain yield (kg plot $^{-1}$) was measured under T_1 = Untreated (Control) respectively.

Grain yield (kg ha $^{-1}$)

The impact of seed treatments on the response of maize plants to management factors, with a particular emphasis on grain yield (kg ha $^{-1}$). Various treatments were implemented and their effects on seed index were investigated. The results indicated that the grain yield (kg ha $^{-1}$) at harvesting stage was (3802.7) under the treatment of T_4 = Seed Priming with canal water (6 hours) after the T_3 then in-oculate with PGPR T_2. Followed by (3545.7) under T_2 = Seed Inoculation with PGPR in-oculum (Biozote Max). The grain yield (kg ha $^{-1}$) at harvesting time of maize crop was further reduced to (3363.7) for T_3 = Seed Priming with canal water (6 hours). The lowest (3039.7) grain yield (kg ha $^{-1}$) was measured under T_1 = Untreated (Control) respectively.

Treatments	**Biological yield (kg ha^{-1})**	**Seed index (1000-grain wt., g)**	**Grain yield (kg plot $^{-1}$)**	**Grain yield (kg ha $^{-1}$)**
T_1 = Untreated (Control)	**5582.8 d**	**243.70 c**	**3.07 d**	**3039.7 d**
T_2 = Seed Inoculation with PGPR in-oculum (Biozote Max)	**7000.1 b**	**293.57 a**	**4.12 b**	**3545.7 b**
T_3 = Seed Priming with canal water (6 hours)	**6009.5 c**	**285.76 b**	**3.65 c**	**3363.7 c**
T_4 = Seed Priming with canal water (6 hours) after the T_3 then in-oculate with PGPR T_2.	**8095.1 a**	**297.74 a**	**4.47 a**	**3802.7 a**
S.E.±	**150.21**	**2.3200**	**0.0913**	**60.203**
LSD	**46.009**	**1.8745**	**1.8091**	**69.912**
P value	**0.0002**	**0.0000**	**0.0000**	**0.0225**

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Discussion

Corn (*Zea mays* L.) is one of the most important cereal crops grown principally during the summer season in Iran. Maize grain is used for both human consumption and poultry feed. This crop has much higher grain protein content than our staple food rice. Based on area and production, maize is the 3rd most important cereal crop after wheat and rice in world. The yield of maize in Iran is very low as compared to other maize producing countries. One of the most important effective factors in increasing corn yield is seed priming with plant growth promoting rhizobacteria (PGPR). Plant growth promoting rhizobacteria (PGPR) are a group of bacteria that actively colonize plant roots and promote growth when added to seeds, roots or tubers have been termed plant-growth-promoting rhizobacteria and increase plant growth and yield (Pereira et al., 2020). Seed inoculation with PGPR significantly increased the plant population in maize crop. Data regarding the effect of seed inoculation with PGPR on plant population. In general, the maximum plant population at germination stage was significantly increased under treatments, with T4 resulting in 47.667 plants. The population was further reduced to 29.000 for untreated treatments. Similar results have been reported by Grover et al. (2021). They reported that inoculation of plants with Rhizobacteria could result in significant changes in various growth parameters, such as plant population. Means of comparisons for maize under different treatments indicated the maximum (16.77) plant population was recorded. The results showed that different seed treatments significantly impacted the plant height in maize crop. Data regarding the effect of maize hybrids and seed inoculation with PGPR on plant height. The highest plant height at maturity stage was (226.21 cm) under T4. The lowest plant height was measured under Untreated (Control) treatment (166.72 cm). Similar results have been reported by Vora et al. (2021), they found maximum plant height (203.12 cm) was obtained to seed inoculation with Rhizobacteria, while the least value (192.55) was recorded without inoculation. Another study according to Khan et al. (2024) reported that inoculation of plants with Azospirillum could result in significant changes in various growth parameters. The study examines the impact of seed application methods on maize plants, focusing on cobs plant^{-1} and stem grith. Results showed that different seed treatments significantly impacted the growth and production of the maize crop. The cobs plant^{-1} at maturity stage was significantly increased (2.11) under the treatment of T_4, with the lowest (1.00) cobs plant^{-1} was observed under untreated treatments. The stem girth at maturity stage was 3.51 under T4. The lowest stem girth was observed to 2.31 under T3. These findings align with the outcomes reported by Santoyo et al. (2021). They found that priming with Zn-lysine chelate (1.5%) and seed inoculation with ZSB significantly increases cob diameter and length in maize plants, leading to improved yield. Seed priming, as noted by Notununu et al. (2022), holds particular significance for maximizing productivity. The significant influence of different seed treatments on maize crop growth and yield. The index increased 297.10 under T4. The lowest seed index was measured 244. 38 under Untreated (Control) treatment. The study also examined the impact of seed application methods on maize plants, focusing on biological yield. The results showed that different seed treatments significantly impacted the growth and production of the maize crop. The highest biological yield at harvesting time was

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observed (8095 kg ha^{-1}) under the treatment T4. The lowest (5582.8 kg ha^{-1}) biological yield was measured under T1. Seed priming and (PGPR) inoculation improved grain and biological yields during the experiment. The application of Rhizobium bacteria has been found to significantly impact various growth parameters and yield-related traits in plants, contributing to overall agricultural productivity Ali et al. (2022) reported that inoculation of plants with Azospirillum could result in significant changes in various growth parameters, such as an increase in total plant biomass Galindo et al. (2022) have suggested that seed priming with PGPR increased dry matter accumulation. The increase in dry matter accumulation with seed priming with PGPR indicates the favorable response of corn hybrids to seed priming with PGPR. Similar observations were also made by Czarnes er al. (2020) in corn. Contreras-Liza et al. (2024) have been reported increase in dry matter accumulation due to inoculation with PGPR. Studies have demonstrated that inoculation with Rhizobium bacteria positively influences plant traits, including but not limited to root development, nutrient absorption, and stress tolerance. Enhanced carbohydrates synthesis and translocation towards grain are the possible reasons behind improved grain and biological yield Haider et al. (2020). Improved biological yield might be due to proper and better nutrition at early stages, which improved early growth of plants and increased dry matter production. Biological yield was increased due to increased leaf area and more plant height Gao et al. (2020). Grain yield is the main target of crop production. The grain yield was significantly affected by both maize crop and seed priming with PGPR. Seed priming with PGPR significantly increased the grain yield. The grain yield varied between 3039.7 kg ha^{-1} in without priming till 3802.7 kg ha^{-1} in seed priming under T_4. These findings are agreed with Ferreira et al. (2020) they have found the maximum yield 5720 kg ha^{-1} was found under various treatments. A similar trend in yield differences across seed priming with PGPR has been reported by Renoud et al (2022). PGPR has been found to increase grain yield in corn hybrids, with maximum yield achieved in plots treated with Azotobacter bacteria, and minimum yield in without seed priming (Marinho et al., 2024).

Conclusions

The results indicate that different integrated seed treatment of priming had a positive and significant influence on the growth and yield of maize. However, based on findings it can be concluded that the better growth and yield of maize crop was obtained at integrated seed treatment of priming with canal water (6 hr) followed by PGPR inoculation consistently demonstrated positive effects on various growth and yield parameters of maize crop.

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