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RESEARCH ARTICLE

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Integrated biofertilizer and inorganic fertilizer management for sustainable growth and yield improvement of hybrid maize (*Zea mays* L.)

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Abstract
The increasing demand for maize production requires fertilization strategies that improve crop productivity while reducing excessive dependence on inorganic fertilizers. This study aimed to evaluate the effect of integrated plant growth-promoting rhizobacteria (PGPR) biofertilizer and NPK inorganic fertilizer management on the growth and yield improvement of BISI-2 hybrid maize. The experiment was conducted from July to October 2022 under polybag cultivation conditions in Proppo Village, Pamekasan Regency, East Java, Indonesia, using a randomized block design with nine PGPR–NPK treatment combinations and three replications. PGPR was applied at 10, 20, and 30 ml L^{-1}, while NPK fertilizer was applied at 0, 1.49, and 2.24 g $plant^{-1}$. Growth parameters, including plant height and root number, were observed at 60 days after planting, while yield parameters, including cob diameter, cob length, seed weight per cob, and 100-seed weight, were measured at harvest. Integrated PGPR and NPK fertilization improved all observed growth and yield parameters, with PGPR 30 ml L^{-1} + NPK 2.24 g $plant^{-1}$ producing the highest values in most traits. Notably, PGPR 30 ml L^{-1} + NPK 1.49 g $plant^{-1}$ showed statistically comparable performance in several parameters, suggesting that this combination may serve as an efficient fertilization option for maintaining maize performance while reducing inorganic fertilizer input. These findings support integrated PGPR–NPK management as a practical strategy for improving BISI-2 hybrid maize productivity and nutrient management efficiency.

KEYWORDS
BISI-2 maize; biofertilizer; NPK fertilizer; PGPR; sustainable nutrient management.

1. INTRODUCTION

Maize (*Zea mays* L.) is one of the most important cereal crops in many tropical agricultural systems because of its wide use as food, animal feed, and industrial raw material. Indonesia relies on maize to support household food needs, livestock production, and agro-industrial development. Rising demand requires productivity improvement through crop management practices that are agronomically effective and environmentally responsible (Datul, 2026). Fertilization remains a major determinant of maize growth and yield because mineral nutrients regulate plant metabolism, root development, photosynthesis, biomass formation, and grain production (Dinar, Marina, Syamsiah, Umyati, & Sukmawati, 2026). However, continuous dependence on inorganic fertilizer alone may create long-term concerns for soil health, nutrient-use efficiency, and production sustainability. Integrated nutrient management that combines inorganic fertilizer with biological inputs has therefore become an important strategy to improve crop productivity while supporting more sustainable agricultural practices.

Previous studies have shown that both inorganic fertilizers and biological inputs can improve maize growth and yield (de Moraes et al., 2026; Karimi, Sayfzadeh, Pazoki, Hadidi Masouleh, & Zakerin, 2025). Nitrogen, phosphorus, and potassium (NPK) fertilization supports maize productivity because nitrogen is closely associated with chlorophyll formation and vegetative growth, phosphorus contributes to energy transfer and root development, and potassium regulates assimilate transport, enzyme activation, and grain filling. Plant growth-promoting rhizobacteria (PGPR) have also been widely recognized as beneficial rhizosphere bacteria that can stimulate plant growth through nitrogen fixation, phosphate solubilization, phytohormone production, siderophore production, and improvement of nutrient uptake. Recent research on maize and sweet corn has examined the effects of NPK fertilizer rates, organic fertilizer, PGPR application, and their combinations on plant height, leaf number, root growth, cob development, and seed weight (Ali & Ali, 2025). These findings indicate that integrated fertilization generally produces better crop responses than the use of a single nutrient source, suggesting that the combination of biofertilizer and inorganic fertilizer offers a promising strategy for improving maize performance.

Despite these advances, evidence on the combined application of PGPR and graded NPK fertilizer rates for specific hybrid maize varieties remains limited, particularly under tropical cultivation conditions (Kakabouki et al., 2025; Risman, Nonkhonman, & Sungthongwises, 2025). Previous studies have mostly emphasized yield improvement, whereas the role of biofertilizer in supporting more efficient inorganic fertilizer use has received less attention. For BISI-2 hybrid maize, limited information is available on whether PGPR integration can maintain or improve vegetative growth and yield components under reduced NPK input. Further evaluation is therefore needed to identify an effective PGPR–NPK combination that improves maize performance while supporting more sustainable fertilizer management.

Based on these considerations, this study hypothesized that the integrated application of PGPR as a biofertilizer and NPK as an inorganic fertilizer would improve the growth and yield performance of BISI-2 hybrid maize more effectively than lower or unbalanced fertilizer combinations. This study aimed to evaluate the effects of different PGPR and NPK fertilizer combinations on vegetative growth, root development, and yield components of hybrid maize. Specifically, plant height, leaf number, root number, cob characteristics, seed weight per cob, and 100-seed weight were assessed under different PGPR–NPK combinations. The significance of this research lies in providing practical and scientific evidence for integrated fertilizer management in maize production, particularly by identifying a fertilizer combination that can enhance crop performance while supporting more sustainable nutrient management in tropical agricultural systems.

2. METHODS

2.1 Material

The experiment was conducted from July to October 2022 in Proppo Village, Proppo District, Pamekasan Regency, East Java, Indonesia. The planting material used in this study was BISI-2 hybrid maize (*Zea mays* L.) seeds. The biofertilizer used was PGPR TaniTech, a commercial liquid plant growth-promoting rhizobacteria (PGPR) product intended to support rhizosphere activity and plant nutrient acquisition. Product information available at the time of the experiment identified PGPR TaniTech as a rhizobacteria-based biofertilizer; however, strain-level microbial composition and viable cell density were not specified on the product label. Therefore, PGPR TaniTech was described in this study based on its commercial function as a PGPR biofertilizer rather than on verified strain-level characterization. The inorganic fertilizer used was NPK Mutiara 16:16:16, which supplied nitrogen, phosphorus, and potassium in balanced proportions. The experiment was conducted using polybags measuring 25 cm × 25 cm filled with soil as the planting medium. The tools used in this study included hoes, analytical scales, measuring tapes, rulers, cameras, labels, scissors, and other supporting cultivation equipment. Soil chemical properties were analyzed before planting to characterize the initial fertility status of the growing medium (Table 1).

Table 1. Initial chemical properties of the soil used in the experiment

Soil chemical property	Estimated value	Unit
Organic C	1.70	%
Total N	0.16	%
Available P	9.50	ppm P
Available K	0.28	cmol(+) kg^{-1}

2.2 Experimental procedure

The experiment was arranged using a randomized block design with three replications. The treatments consisted of nine combinations of PGPR and NPK fertilizer doses: P1N1 = PGPR 10 ml L^{-1} without NPK; P1N2 = PGPR 10 ml L^{-1} + NPK 1.49 g $plant^{-1}$; P1N3 = PGPR 10 ml L^{-1} + NPK 2.24 g $plant^{-1}$; P2N1 = PGPR 20 ml L^{-1} without NPK; P2N2 = PGPR 20 ml L^{-1} + NPK 1.49 g $plant^{-1}$; P2N3 = PGPR 20 ml L^{-1} + NPK 2.24 g $plant^{-1}$; P3N1 = PGPR 30 ml L^{-1} without NPK; P3N2 = PGPR 30 ml L^{-1} + NPK 1.49 g $plant^{-1}$; and P3N3 = PGPR 30 ml L^{-1} + NPK 2.24 g $plant^{-1}$. Each treatment was replicated three times, resulting in 27 experimental units. Each experimental unit consisted of one polybag containing one maize plant. Therefore, one plant was observed per experimental unit, resulting in 27 sample plants for growth and yield measurements.

The planting medium was prepared by filling 25 cm × 25 cm polybags with soil. One maize seed was planted in each polybag. Plant maintenance included replanting, fertilization, watering, weeding, pest and disease control, and harvesting. Replanting was carried out five days after planting to replace dead or abnormal plants. PGPR was diluted according to the assigned treatment concentration and applied once a week by spraying the solution onto the stem, leaves, and root zone. This application method was used to expose both aboveground plant surfaces and the rhizosphere area to the PGPR solution. NPK fertilizer was applied twice during the growing period. The first application was given at 18 days after planting using one-third of the total dose, while the second application was given at 35 days after planting using the remaining dose. NPK fertilizer was placed approximately 7 cm from the stem in a small hole and then covered with soil. Watering was carried out twice daily, in the morning and afternoon. Weeds were controlled manually, while pest and disease control was conducted once a week using pesticide. Harvesting was conducted when maize reached physiological maturity, indicated by dry yellowish husks and the appearance of a black layer at the base of the kernels (Sary & Abd El-Aziz, 2025).

2.3 Growth and biomass measurements

Growth measurements were conducted at 60 days after planting to evaluate the vegetative response of BISI-2 hybrid maize to the PGPR and NPK fertilizer combinations. The growth parameters observed in this study were plant height and number of roots. Plant height was measured from the base of the plant to the growing point using a measuring tape. The number of roots was determined by carefully removing the sample plant from the growing medium and counting the roots formed on each plant. The original study included plant height and root number as growth parameters measured from sampled plants.

Yield measurements were conducted at harvest when the maize plants reached physiological maturity. The yield parameters observed in this study were cob diameter, cob length, seed weight per cob, and 100-seed weight. Cob diameter was measured on husked cobs using a measuring tape, while cob length was measured from the base to the tip of the cob. Seed weight per cob was determined by weighing the shelled kernels obtained from each cob. The 100-seed weight was measured by weighing 100 kernels from each sample plant (Moradi & Siosemardeh, 2025). These selected yield traits were used to represent cob development and grain yield components under different PGPR and NPK fertilizer combinations.

2.4 Data analysis

The data were analyzed using analysis of variance at the 5% significance level to determine the effect of PGPR and NPK fertilizer combinations on maize growth and yield parameters. When the analysis of variance indicated a significant treatment effect, mean comparisons were performed using the Least Significant Difference test at the 5% significance level. This statistical approach follows the original data analysis procedure, which used analysis of variance followed by LSD testing when significant treatment effects were detected. In addition, Pearson correlation analysis was performed to examine the relationships among the selected growth and yield parameters, including plant height, number of roots, cob diameter, cob length, seed weight per cob, and 100-seed weight. The correlation coefficients were visualized using a heatmap to provide an integrated overview of trait associations under different PGPR and NPK fertilizer combinations. When individual replicate data are available, the correlation analysis should be calculated using all experimental observations. If only treatment means are used, the heatmap should be interpreted as a descriptive correlation analysis based on treatment mean values rather than as direct causal evidence.

3. RESULT AND DISCUSSION

3.1 Vegetative growth

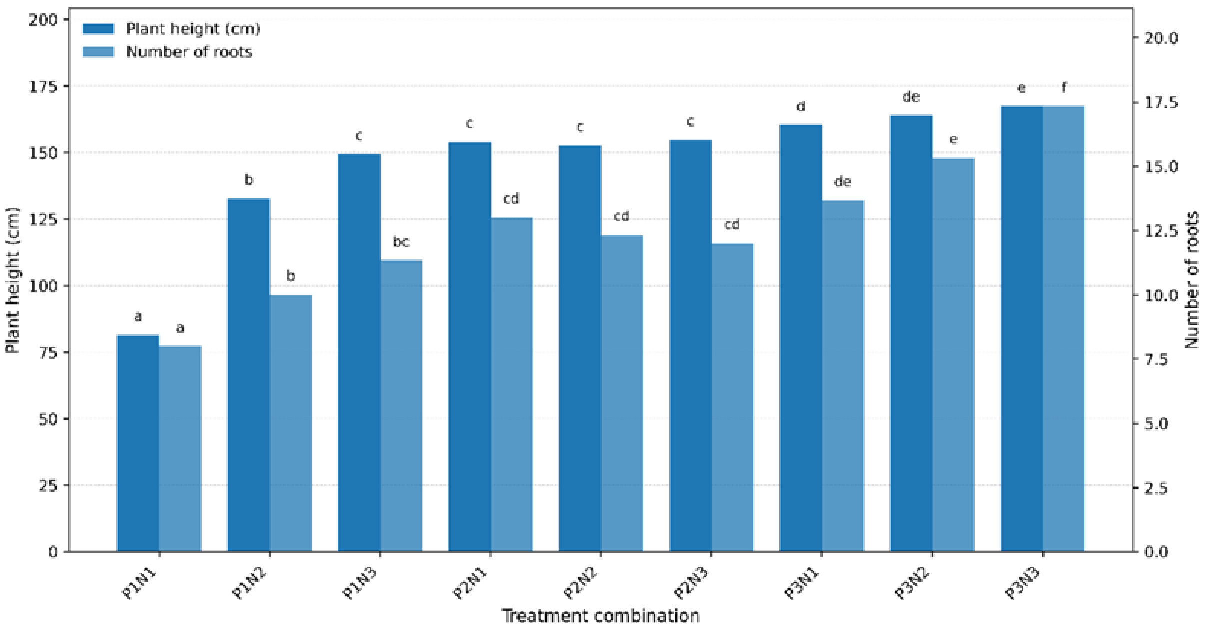

Figure 1. Plant growth response of BISI-2 hybrid maize at 60 days after planting

Vegetative growth was evaluated through plant height and root number of BISI-2 hybrid maize at 60 days after planting. The PGPR–NPK combinations improved both growth parameters, as presented in Figure 1. Plant height increased from 81.50 cm under P1N1 to 167.33 cm under P3N3, representing an increase of approximately 105.3% compared with the lowest treatment. Root number also increased from 8.00 roots under P1N1 to 17.33 roots under P3N3, or approximately 116.6% higher than the lowest treatment. P3N3 produced the highest plant height, although this value was not significantly different from P3N2 based on the LSD test at the 5% level. Root number showed a stronger treatment response, with P3N3 being significantly higher than all other treatments. These results indicate that PGPR 30 ml L^{-1} combined with NPK 2.24 g $plant^{-1}$ provided the most favorable condition for vegetative growth of BISI-2 hybrid maize.

Improved vegetative growth under the integrated treatment was likely associated with the complementary contribution of rhizosphere stimulation and mineral nutrient supply. PGPR can support early plant development by improving nutrient availability, stimulating root growth, and enhancing rhizosphere activity through mechanisms such as phytohormone production, nitrogen fixation, phosphate solubilization, and potassium mobilization (Kurt, 2025). Stronger root development may increase the capacity of maize plants to absorb water and nutrients, which subsequently supports shoot elongation and biomass formation (El-Akhdar, Elhawat, Shabana, Aboelsoud, & Alshaal, 2025). NPK fertilizer also supplies essential macronutrients required for cell division, photosynthesis, and structural growth. The higher values observed under P3N3 therefore suggest that adequate mineral nutrient supply created favorable conditions for PGPR to support vegetative development more effectively.

These findings are consistent with previous studies reporting positive effects of PGPR and mineral fertilizer integration on maize growth. PGPR-based biostimulant combined with half-dose NPK-urea improved maize height, leaf area, thousand-grain weight, grain yield, and nutrient uptake compared with farmer practice (Imran, 2024). Integrated organic nutrient management improved maize growth and supported cleaner maize production, indicating that biologically based nutrient management can strengthen crop development when mineral nutrition is available (Kumar et al., 2024). PGPR combined with 50% of the recommended nitrogen rate produced corn biomass and nitrogen concentration equal to or greater than the full nitrogen rate without PGPR. The present study supports these earlier findings by showing that integrated PGPR and NPK management improved both plant height and root number in BISI-2 hybrid maize. Notably, P3N2 produced plant height statistically comparable to P3N3, suggesting that PGPR 30 ml L^{-1} combined with a moderate NPK dose may also be a promising option for improving vegetative growth with lower inorganic fertilizer input. (Karimi et al., 2025).

3.2 Cob development

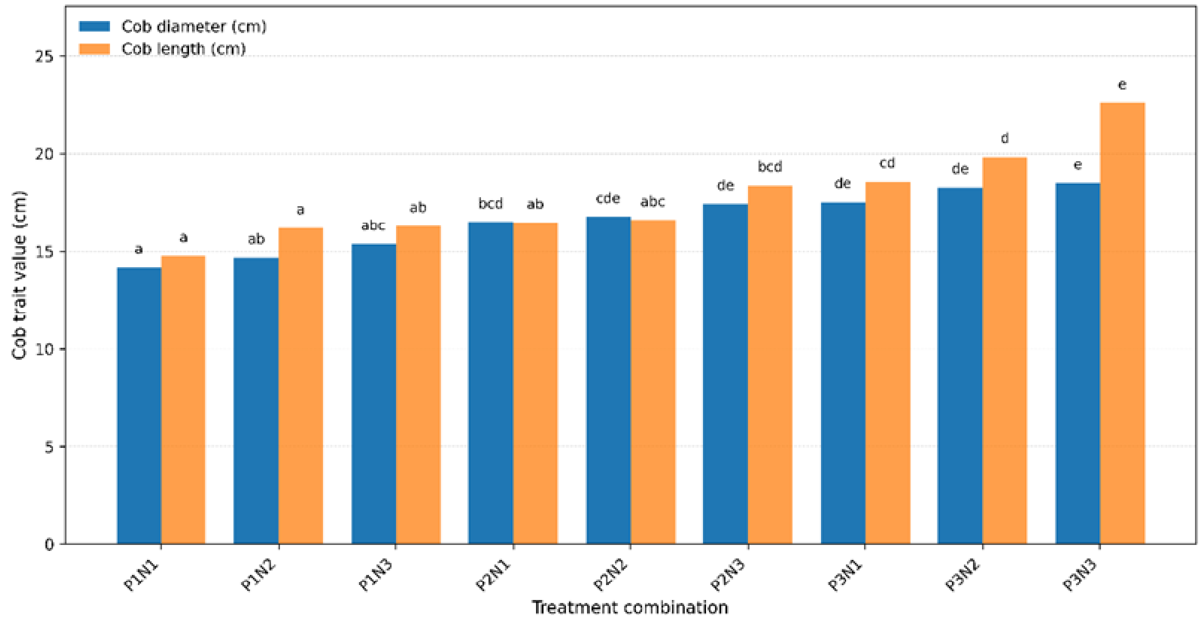

Figure 2. Cob development of BISI-2 hybrid maize at 60 days after planting

Cob development was evaluated using cob diameter and cob length as yield-related traits of BISI-2 hybrid maize. The PGPR–NPK combinations improved both cob traits, as presented in Figure 2. Cob diameter increased from 14.17 cm under P1N1 to 18.50 cm under P3N3, representing an increase of approximately 30.6% compared with the lowest treatment. Cob length also increased from 14.77 cm under P1N1 to 22.60 cm under P3N3, or approximately 53.0% higher than the lowest treatment. P3N3 produced the highest cob diameter, although this value was statistically comparable to several intermediate and high-input combinations, including P2N2, P2N3, P3N1, and P3N2 based on the LSD test at the 5% level. Cob length showed a stronger response to the highest fertilizer combination, with P3N3 being significantly higher than all other treatments. These results indicate that PGPR 30 ml L^{-1} combined with NPK 2.24 g $plant^{-1}$ was the most favorable treatment for improving cob development, particularly cob elongation.

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Enhanced cob development under P3N3 was likely associated with better nutrient availability during the transition from vegetative growth to reproductive organ formation. Stronger root development under integrated PGPR–NPK fertilization, as described in the previous subsection, may have supported nutrient uptake capacity and subsequently contributed to cob expansion. PGPR can improve nutrient acquisition and rhizosphere functionality through mechanisms related to nitrogen fixation, phosphate solubilization, siderophore production, phytohormone production, and microbial community modulation (Bhaumik, Kashyap, & Ghosh Bag, 2024). Rather than acting independently, these biological effects may complement NPK fertilizer by improving the availability and uptake of nutrients required for assimilate production and reproductive development. The larger cob size under P3N3 therefore suggests that sufficient mineral nutrient supply, supported by PGPR-mediated rhizosphere activity, contributed to more favorable cob formation. Previous fertilizer studies also reported that cob length can increase linearly with NPK application, and this response has been associated with improved photosynthetic activity and better cob size and quality under sufficient nutrient supply (Chauhan, Shah, Patel, Shroff, & Patel, 2024).

Stronger root development under integrated PGPR–NPK fertilization, as described in the previous subsection, may have supported nutrient uptake capacity and subsequently contributed to cob expansion

The present findings are consistent with earlier studies showing that nutrient-based management can improve maize cob traits. Abbas et al. (2024) reported that organic fertilizer affected cob diameter and 100-seed weight in maize, with the highest cob diameter obtained under the highest organic fertilizer dose tested. The same study also showed that phosphate and potassium uptake were correlated with plant biomass and root length, indicating that nutrient uptake is closely connected with yield formation in maize. Field-based evaluation of multi-strain PGPR further confirmed that PGPR application improved maize productivity and ear traits under field conditions. Research on NPK fertilization also showed that different NPK levels significantly affected cob length and cob diameter, with higher nutrient availability generally producing better cob characteristics than unfertilized control treatments (DahPahlavan, Farnia, Jafarzadeh Kenarsari, & Nakhjavan, 2023). Therefore, the higher cob diameter and cob length observed under P3N3 support the view that combining PGPR biofertilizer with NPK fertilizer can improve cob development in hybrid maize.

Research on NPK fertilization also showed that different NPK levels significantly affected cob length and cob diameter, with higher nutrient availability generally producing better cob characteristics than unfertilized control treatments

3.3 Grain yield components

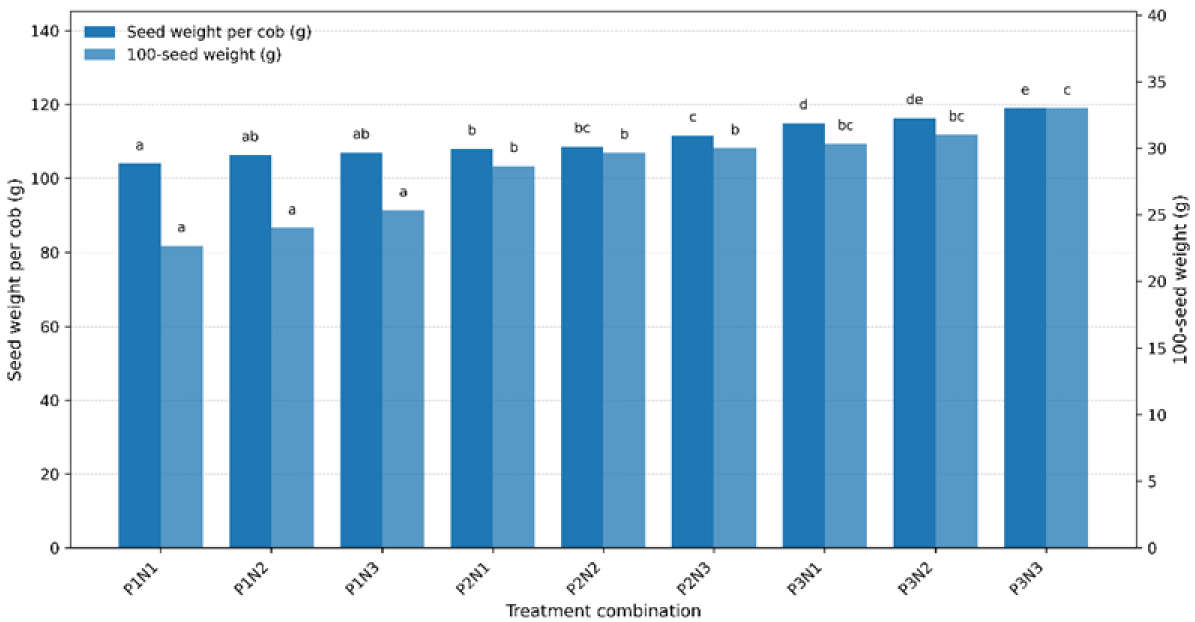

Figure 3. Grain yield components of BISI-2 hybrid maize at 60 days after planting

Grain yield components were evaluated using seed weight per cob and 100-seed weight, which represent assimilate accumulation in kernels during the grain-filling stage. The integrated application of PGPR and NPK fertilizer improved both grain parameters, as presented in Figure 3. Seed weight per cob increased from 104.00 g under P1N1 to 119.00 g under P3N3, equal to an increase of approximately 14.4%. The 100-seed weight increased more sharply, from 22.67 g under P1N1 to 33.00 g under P3N3, equal to an increase of approximately 45.6%. P3N3 produced the highest seed weight per cob, although this value was not significantly different from P3N2 based on the LSD test at the 5% level. The 100-seed weight also reached the highest value under P3N3, but it was statistically comparable to P3N2 and P3N1. This pattern indicates that the highest PGPR concentration supported stronger kernel development, while increasing NPK from 1.49 to 2.24 g plant^{-1} did not always produce a significant additional increase in final grain weight.

Improved seed weight per cob and 100-seed weight were likely related to better nutrient supply and assimilate partitioning during kernel development. Combined NPK fertilization has been reported to increase grain-filling rate, grain-filling duration, grain volume, and grain yield in maize, indicating that balanced nitrogen, phosphorus, and potassium availability is important for kernel formation (Behrouzi, Diyanat, Majidi, Mirhadi, & Shirkhani, 2023). Nitrogen supports photosynthetic capacity and protein synthesis, phosphorus contributes to energy transfer required for reproductive development, and potassium regulates photosynthate transport and dry matter translocation to the grain (Kakabouki et al., 2025). Building on the improved vegetative growth and cob development described in the previous subsections, the higher grain yield components under P3N3 suggest that integrated PGPR–NPK fertilization supported a more favorable source–sink relationship during grain filling.

These results are consistent with previous studies showing that PGPR and balanced fertilization can improve maize yield components. Kurt (2025) reported that a PGPR-based biostimulant combined with half-dose NPK-urea improved maize yield performance, including thousand-grain weight and grain yield, compared with farmers' practice. Selected PGPR strains were positive for nitrogen fixation, phosphate solubilization, and auxin production, and that PGPR inoculation increased maize ear yield by up to 30.9% with reduced fertilizer-N input. Field evaluation of multi-strain PGPR also confirmed that PGPR application significantly improved maize productivity and grain yield under semi-arid field conditions (El-Akhdar et al., 2025). The present study supports these findings by showing that PGPR 30 ml L^{-1} combined with NPK 2.24 g plant^{-1} produced the highest seed weight per cob and 100-seed weight in BISI-2 hybrid maize. However, the statistically comparable performance of P3N2 on both grain parameters suggests that PGPR 30 ml L^{-1} combined with NPK 1.49 g plant^{-1} may be a promising option for maintaining grain performance with lower inorganic fertilizer input.

3.4 Integrated Relationship among Growth and Yield Traits Based on Heatmap Analysis

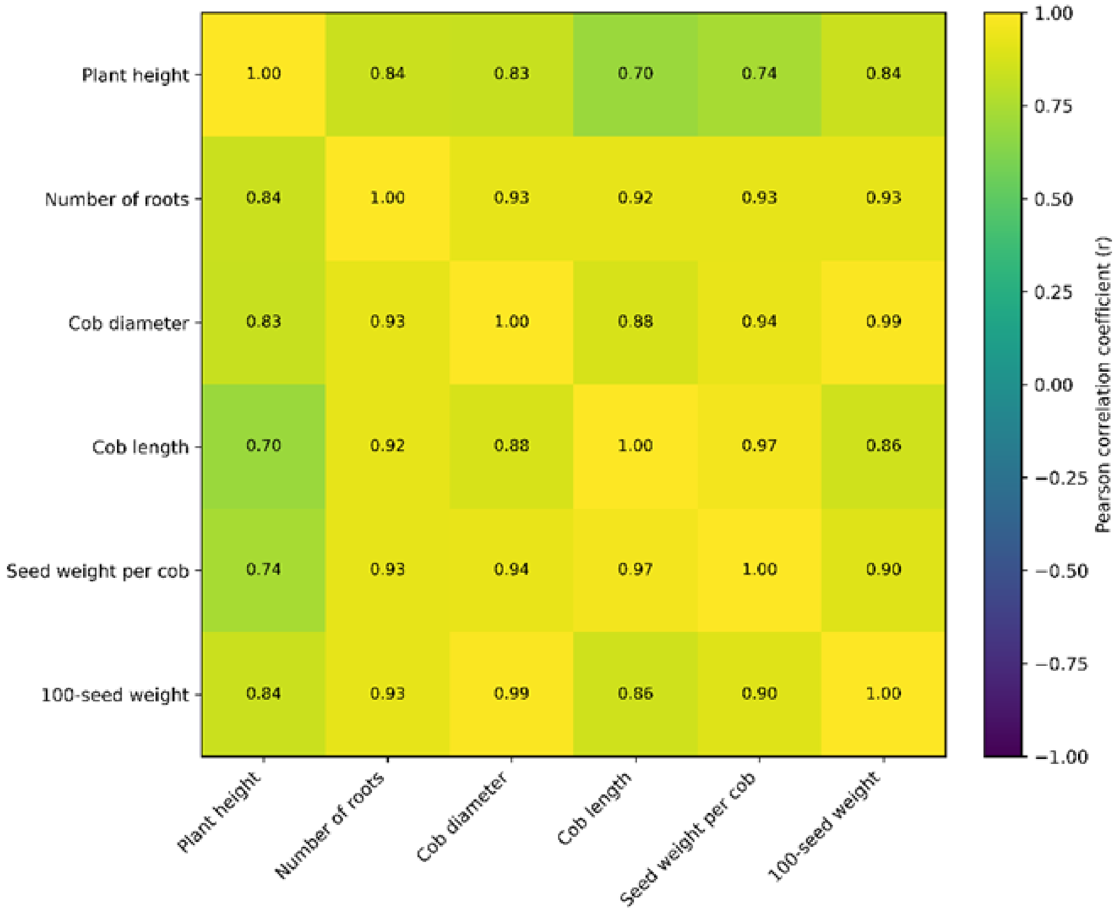

Figure 4. Correlation heatmap among growth and yield parameters of BISI-2 hybrid maize at 60 days after planting

The correlation heatmap provided an integrated overview of the relationships among selected growth and yield parameters of BISI-2 hybrid maize under different PGPR–NPK combinations. Correlation strength was interpreted based on the absolute correlation coefficient (|r|), with values categorized as weak (0.10–0.39), moderate (0.40–0.69), strong (0.70–0.89), and very strong (≥0.90). All observed parameters showed positive correlations, as presented in Figure 4, indicating that improvement in one trait was generally associated with improvement in other traits. Very strong relationships were observed between cob diameter and 100-seed weight (r = 0.99), cob length and seed weight per cob (r = 0.97), cob diameter and seed weight per cob (r = 0.94), root number and seed weight per cob (r = 0.93), and root number and cob diameter (r = 0.93). These patterns suggest that root development, cob formation, and kernel weight were closely associated within the integrated fertilization treatments. Plant height showed strong correlations with cob length (r = 0.70) and seed weight per cob (r = 0.74), indicating that taller plants were associated with yield-related traits, although the relationships were weaker than those observed among root, cob, and grain parameters.

The positive trait associations indicate a coordinated relationship between vegetative development and yield formation. The strong correlation between root number and yield-related traits suggests that root development may contribute to nutrient and water uptake capacity, which later supports cob and seed formation (Ali & Ali, 2025). The close relationship between cob traits and grain traits also indicates that improved cob development may provide a stronger structural and physiological basis for kernel filling. Nevertheless, because the heatmap was generated from treatment mean values rather than individual replicate data, these correlations should be interpreted as descriptive associations rather than direct causal evidence. Overall, the heatmap supports the broader finding that integrated biofertilizer and inorganic fertilizer management produced coordinated improvements across vegetative and yield components of BISI-2 hybrid maize.

4. CONCLUSION

This study evaluated the effect of integrated PGPR biofertilizer and NPK inorganic fertilizer management on the growth and yield improvement of BISI-2 hybrid maize. The combined application of PGPR and NPK significantly improved maize performance, particularly plant height, root number, cob diameter, cob length, seed weight per cob, and 100-seed weight. PGPR 30 ml L^{-1} combined with NPK 2.24 g $plant^{-1}$ produced the highest values in most observed parameters, indicating that this combination provided the most favorable condition for maize growth and yield formation. However, several traits under PGPR 30 ml L^{-1} combined with NPK 1.49 g $plant^{-1}$ were statistically comparable to the highest NPK dose. This finding suggests that P3N2 may serve as a practical alternative strategy for maintaining strong maize growth and yield performance while reducing inorganic fertilizer input compared with the highest NPK treatment.

The correlation heatmap further indicated positive relationships among growth and yield parameters, showing that improved vegetative growth, cob development, and grain yield components were closely associated under integrated fertilization. These findings highlight the potential of PGPR–NPK integration as a sustainable nutrient management strategy for improving hybrid maize productivity and supporting more efficient inorganic fertilizer use. From a practical perspective, PGPR 30 ml L^{-1} combined with NPK 1.49 g $plant^{-1}$ can be considered a promising fertilizer management option for sustainable maize cultivation, particularly when the objective is to reduce inorganic fertilizer input without substantially compromising crop performance. Future studies should evaluate this integrated fertilization strategy under multi-season field conditions and include pre- and post-harvest soil chemical and biological analyses, nutrient-use efficiency measurements, and residual soil fertility assessment to better explain its long-term agronomic and soil-related effects in maize production systems.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Mubarok Mubarok: Funding acquisition, Conceptualization. Lia Kristiana: Conceptualization, Funding acquisition, Writing – original draft, Supervision. Marchel Putra Garfansa: Writing – original draft, Writing – review & editing.

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ETHICS APPROVAL

No ethical approval was needed for this study.

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CONFLICT OF INTEREST

The author declares no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data available by request.

REFERENCES

Abbas, M., Tian, C., Nagy, M. K. I., Al-Metwally, M. S., Chen, X., & Abdel-Lattif, H. M. (2024). Synergistic Effect of Iron and Zinc Nanoparticles with Recommended Nitrogen Dose on Production and Grain Quality of Maize (Zea mays L.) Cultivars Under Drought Stress. *Nitrogen, 5*(4), 1156-1180. doi:https://doi.org/10.3390/nitrogen5040074

Ali, S., & Ali, A. (2025). Integrated Single Superphosphate with Cattle Manure Increased Growth, Yield, and Phosphorus Availability of Maize (Zea mays L.) Under Rainfed Conditions. *Nitrogen, 6*(1), 9. doi:https://doi.org/10.3390/nitrogen6010009

Behrouzi, D., Diyanat, M., Majidi, E., Mirhadi, M. J., & Shirkhani, A. (2023). Yield and quality of forage maize as a function of diverse irrigation regimes and biofertilizer in the west of Iran. *Journal of Plant Nutrition, 46*(10), 2246-2256. doi:https://doi.org/10.1080/01904167.2022.2155539

Bhaumik, S., Kashyap, R., & Ghosh Bag, A. (2024). Effect of essential plant nutrients on growth and yield of maize crop (Zea mays L.): a review. *Vegetos, 37*(5), 1705-1719. doi:https://doi.org/10.1007/s42535-024-01024-w

Chauhan, Z. Y., Shah, S. N., Patel, K. C., Shroff, J. C., & Patel, H. K. (2024). Optimizing integrated nutrient management for sustainable maize–sesame cropping in Gujarat Plains: A soil health perspective. *Soil Science Society of America Journal, 88*(3), 846-857. doi:https://doi.org/10.1002/saj2.20664

DahPahlavan, S., Farnia, A., Jafarzadeh Kenarsari, M., & Nakhjavan, S. (2023). Bio-organic and chemical integrated amendments; responses for corn growth (Zea mays L.) and nitrate accumulation. *Cereal Research Communications, 51*(4), 891-903. doi:https://doi.org/10.3390/plants13101331

Datul, E. (2026). Enhanced Yield of Green Corn Through Biofertilizer and Foliar Fertilizer Application in Double-Row Corn Planting Technology. *International Journal of Sustainability and Advanced Integrated Research, 2*(2), 636-641. doi:https://doi.org/10.65339/ijsair.V2.I2.231

de Moraes, V. C., Ruivo, L. B., Zeny, P. M., Barboza, L. E., Schiebelbein, L. M., Matiello, R. R., . . . Ohse, S. (2026). In field conditions the combined application of aqueous extracts from the cyanobacterium Arthrospira platensis (seeds) and the microalga Nannochloropsis oculata (foliar) enhanced the corn (Zea mays L.) yield. *Journal of Applied Phycology, 38*(1), 455-466. doi:https://doi.org/10.1007/s10811-025-03767-8

Dinar, D., Marina, I., Syamsiah, M., Umyati, S., & Sukmawati, D. (2026). Comparative Analysis of Integrated Crop Management (ICM) Implementation on Hybrid Maize Production and Farmers' Income (Zea mays L.). *Jurnal Penelitian Pendidikan IPA, 12*(2), 731-737. doi:https://doi.org/10.29303/jppipa.v12i2.14306

El-Akhdar, I., Elhawat, N., Shabana, M. M. A., Aboelsoud, H. M., & Alshaal, T. (2025). Physiological and Agronomic Responses of Maize (Zea mays L.) to Compost and PGPR Under Different Salinity Levels. *Plants, 14*(10), 1539.

doi:https://doi.org/10.3390/plants14101539

Imran. (2024). Integration of organic, inorganic and bio fertilizer, improve maize-wheat system productivity and soil nutrients. *Journal of Plant Nutrition, 47*(15), 2494-2510. doi:https://doi.org/10.1080/01904167.2024.2354190

Kakabouki, I., Roussis, I., Mavroeidis, A., Stavropoulos, P., Kanatas, P., Pantaleon, K., . . . Tigka, E. (2025). Effects of Zeolite Application and Inorganic Nitrogen Fertilization on Growth, Productivity, and Nitrogen and Water Use Efficiency of Maize (Zea mays L.) Cultivated Under Mediterranean Conditions. *Sustainability, 17*(5), 2178. doi:https://doi.org/10.3390/su17052178

Karimi, M., Sayfzadeh, S., Pazoki, A., Hadidi Masouleh, E., & Zakerin, H. R. (2025). Effects of bio-fertilizers and nitrogen levels on yield and quality of single-cross maize (KSC 704). *Journal of Plant Nutrition, 48*(12), 1987-2003. doi:https://doi.org/10.1080/01904167.2025.2462718

Kumar, A., Singh, R., Babu, S., Avasthe, R. K., Das, A., Pandey, A., . . . Rathore, S. S. (2024). Integrated organic nutrient management: a sustainable approach for cleaner maize (Zea mays L.) production in the Indian Himalayas. *Organic Agriculture, 14*(3), 373-393. doi:10.1007/s13165-024-00471-8

Kurt, P. O. (2025). Field-based evaluation of multi-strain PGPR to improve zea mays yield and soil nutrient dynamics in semi-arid of Türkiye. *Scientific Reports, 15*(1), 22553. doi:https://doi.org/10.1038/s41598-025-07643-w

Moradi, L., & Siosemardeh, A. (2025). Bio and chemical fertilizers integration supplemented by biostimulants a sustainable way to reduce chemical inputs in rainfed wheat systems. *Scientific Reports, 15*(1), 45264. doi:https://doi.org/10.1038/s41598-025-29783-9

Risman, R. D. S., Nonkhonman, C., & Sungthongwises, K. (2025). Integrating vermicompost, black soldier fly, and inorganic fertilizers enhances corn growth and yield. *Heliyon, 11*(1). doi:https://doi.org/10.1016/j.heliyon.2024.e41314

Sary, D. H., & Abd El-Aziz, M. E. (2025). Synthesis and characterization of nano-micronutrient fertilizer and its effect on nutrient availability and maize (Zea Mays L.) productivity in calcareous soils. *Scientific Reports, 15*(1), 25838. doi:https://doi.org/10.1038/s41598-025-11273-7