

Demonstration Trial: Evaluating the efficacy of Phosphonate to control Garlic Rust

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Introduction

Garlic (*Allium sativum* L.) is an important horticultural crop cultivated worldwide for its nutritional, medicinal, and economic value (Gebreyohannes & Gebreyohannes, 2013; Singh et al., 2014). In Bhutan, garlic production, particularly in districts such as Gasa, contributes significantly to household income, food security, and the country's organic agriculture objectives. However, national garlic production has experienced considerable fluctuations in recent years. Garlic production reached 760.89 tonnes in 2019 but subsequently declined by more than 60% in the following years (FAOSTAT, 2023). This decline has been attributed not only to climatic variability and agronomic constraints but also to increasing disease pressure, particularly garlic rust (*Puccinia allii*) (Anjomshoaa et al., 2020; Belay et al., 2024).

Garlic rust has emerged as one of the most economically important foliar diseases affecting garlic production in Bhutan, especially under the cool and humid environmental conditions prevalent in high-altitude regions such as Gasa. Infection by the pathogen reduces photosynthetic activity and accelerates leaf senescence, resulting in smaller bulb size and reduced marketable yield (Koike et al., 2001; Mengesha & Tesfaye, 2015). Farmers in affected areas have reported yield losses ranging from 40–50%, with disease symptoms often appearing as early as the 4–5 leaf growth stage (Belay et al., 2024). Furthermore, the expansion of garlic cultivation under monocropping systems, particularly in Khatoe Gewog, has increased disease risk through inoculum buildup and limited crop rotation practices (Reuveni et al., 1996).

Current disease management strategies largely depend on synthetic fungicides. However, their use is associated with challenges such as high input costs, environmental concerns, and potential incompatibility with Bhutan's organic farming policies (Abbey et al., 2019; Hahn, 2014). These limitations highlight the need for safer, effective, and environmentally sustainable alternatives for garlic rust management.

Potassium phosphite, a phosphonate-based compound, has demonstrated systemic antifungal activity and the ability to induce plant defence mechanisms against several plant pathogens, including *Phytophthora*, *Pythium*, and downy mildew pathogens (Guest & Grant, 1991; Ribeiro Chagas et al., 2020). Its low toxicity, reduced environmental impact, and compatibility with sustainable production systems make it a promising option for integrated disease management (Havlin & Schlegel, 2021; Kowata et al., 2012). Previous studies conducted in Bhutan have demonstrated its effectiveness in managing *Phytophthora* blight in

chili (NPPC, 2023); however, information regarding its effectiveness against garlic rust caused by *Puccinia allii* remains limited.

This demonstration trial was conducted as a collaborative initiative with the Plant Pathology Program of the National Plant Protection Centre (NPPC). The Agricultural Research and Development Centre (ARDC), Bajo, was responsible for trial establishment, treatment application, and data collection.

The study was conducted to evaluate the field efficacy of potassium phosphite in managing garlic rust under farmer-managed conditions in Gasa and to promote its adoption as a sustainable and environmentally friendly plant protection alternative.

Objectives

1. To evaluate the efficacy of potassium phosphite in managing garlic rust under field conditions.
2. To promote the use of potassium phosphite as an effective and environmentally friendly plant protection product.

Materials and Methods

Study Site

The demonstration trial was conducted in four farmers' fields in Gasa District, with two sites located in Khamoed Gewog and two sites in Khatoe Gewog. These farms were selected because they had been affected by garlic rust disease in previous production years, and garlic is one of the major cash crops grown in Gasa.

Planting Material

Healthy local garlic cultivars susceptible to rust infection were used as planting materials.

Experimental Design

Four experimental trials were established at four different sites, with two sites in Khatoe and two sites in Khamoed. The study focused on site-specific management of garlic rust. Since the two locations differed in elevation, sowing dates varied accordingly, resulting in different implementation timelines. Based on observations and challenges encountered during the previous season, the experimental plot size was reduced to facilitate effective trial management and data collection.

A Randomized Complete Block Design (RCBD) was employed with four replications per treatment. The following three treatments were evaluated:

- **Treatment 1 (Targeted Application):** Potassium phosphite was applied at 95, 150, and 240 days after planting (DAP), targeting critical crop growth stages.
- **Treatment 2 (Calendar-Based Application):** Potassium phosphite was applied at 14-day intervals, commencing at 95 DAP.
- **Treatment 3 (Control):** An equivalent volume of water was applied.

Each plot consisted of six rows, each measuring 2 m in length. Plant spacing was maintained at 0.1 m within rows and 0.3 m between rows. A buffer zone of 0.5 m was maintained between treatment plots and replications. The net plot size was 4 m² (2 m × 2 m), while the total gross experimental area was 75 m².

Uniform-sized local garlic bulbs were planted in well-prepared beds. All plots received uniform applications of recommended fertilizers and standard agronomic practices, including irrigation and weeding.

Disease incidence and severity data were collected from ten randomly selected pre-tagged plants within each plot. Data collection commenced at the vegetative stage (4–5 leaf stage, approximately 95 DAP) and continued at 14-day intervals until harvest. Disease assessments were conducted before each treatment application.

Treatment Application

Treatment 1: Targeted Application

Potassium phosphite applications were carried out at predetermined critical growth stages of the garlic crop. The first application was made at 95 DAP during the active vegetative growth stage. Subsequent applications were made at 150 DAP and 240 DAP to provide protection during important developmental stages.

To minimize spray drift between adjacent plots, a 2 m high tarpaulin sheet was installed during spraying. This measure helped reduce experimental bias arising from the relatively small plot size. A manual knapsack sprayer was used for all treatment applications.

Treatment 2: Calendar-Based Application

Under this treatment, potassium phosphite was applied at regular 14-day intervals. The first application was made at 95 DAP during the vegetative stage (4–5 leaf stage) as a preventive measure against garlic rust. Applications continued every 14 days until the crop reached physiological maturity.

Data Collection

Disease data were collected at 14-day intervals beginning at 95 DAP and continued until harvest. Assessments were conducted on ten pre-tagged plants within each plot. All observations were recorded using the Epicollect mobile application.

Yield-Related Parameters

Yield-related data were collected from the same ten tagged plants in each plot. Plant height, bulb weight, and bulb diameter were measured using appropriate measuring instruments.

Data Analysis

Data were analysed using R statistical software. Linear Mixed Models (LMMs) were fitted to evaluate the effects of location, treatment, and their interaction on plant height, bulb weight, and bulb diameter, with replication treated as a random effect. Type III ANOVA with Satterthwaite's method was used to test the significance of fixed effects. Mean separation was performed using estimated marginal means with Tukey-adjusted pairwise comparisons at $P < 0.05$.

Results and discussion

Garlic rust did not develop during the experimental period, resulting in zero disease incidence and severity across all treatments and assessment dates. Therefore, disease data were not subjected to statistical analysis. Nevertheless, agronomic and yield-related parameters were collected and analysed to evaluate treatment effects, and the results are presented below.

Effect of treatment on plant height

Plant height was significantly affected by location ($F_{2,24} = 1123.11$, $P < 0.001$). Garlic grown in different locations exhibited substantial variation in height, highlighting the strong influence of local environmental conditions on crop growth. In contrast, treatment had no significant effect on plant height ($F_{2,24} = 0.16$, $P = 0.853$). However, a significant location $\times$ treatment interaction was detected ($F_{4,24} = 3.64$, $P = 0.019$), indicating that treatment performance varied across locations.

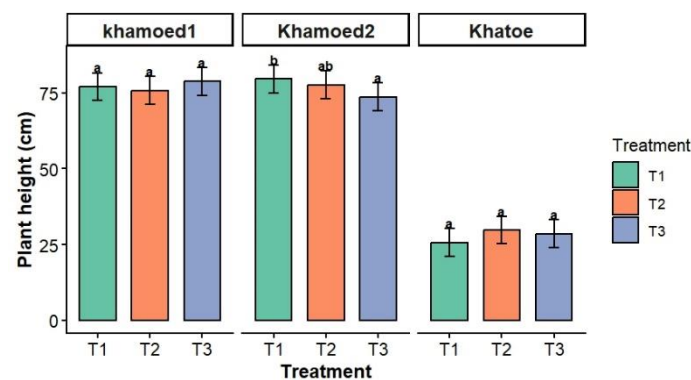


Figure 1. Mean garlic plant height under different treatments across three locations. Error bars represent $\pm$ standard error. Bars sharing the same letter are not significantly different according to estimated marginal means comparisons ($P < 0.05$).

Effect of treatment on bulb weight

Bulb weight was significantly affected by location ($F_{2,27} = 100.17$, $P < 0.001$) and treatment ($F_{2,27} = 5.01$, $P = 0.014$). The interaction between location and treatment was not significant ($F_{4,27} = 0.62$, $P = 0.649$). Although treatment means differed numerically within locations, Tukey-adjusted pairwise comparisons did not detect significant differences among treatments within individual locations ($P > 0.05$).

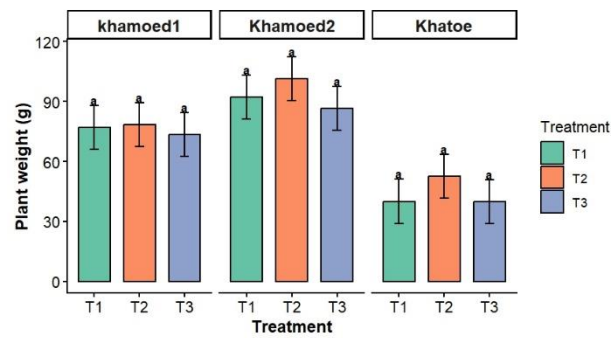


Figure 2. Mean garlic bulb weight under different treatments across three locations. Error bars represent $\pm$ standard error. Bars sharing the same letter are not significantly different according to estimated marginal means comparisons ($P < 0.05$).

Effect of treatment on bulb diameter

Analysis using a linear mixed model revealed that bulb diameter was significantly affected by location ($F_{2,27} = 92.89$, $P < 0.001$). In contrast, treatment had no significant effect on bulb diameter ($F_{2,27} = 2.16$, $P = 0.135$). The interaction between location and treatment was also not significant ($F_{4,27} = 1.26$, $P = 0.309$), indicating that treatment responses were consistent across locations.

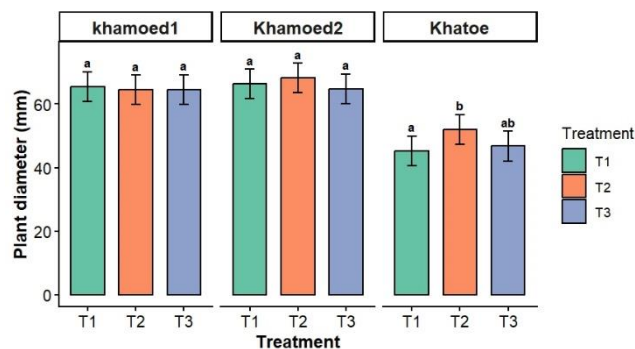


Figure 3. Mean garlic bulb diameter under different treatments across three locations. Error bars represent $\pm$ standard error. Bars sharing the same letter are not significantly different according to estimated marginal means comparisons ($P < 0.05$).

Plant height was significantly influenced by location, while treatment had no significant overall effect. The highly significant location effect indicates that environmental conditions differed substantially among the study sites and strongly influenced garlic vegetative growth. Variations in soil fertility, temperature, moisture availability, and altitude among locations may have contributed to the observed differences in plant height. Garlic growth is highly responsive to environmental conditions, and favourable growing environments promote greater vegetative development and plant vigor. The significant location $\times$ treatment interaction further suggests

that treatment responses varied depending on the environmental conditions of each site, indicating that the effectiveness of management interventions may be location-specific. Similar findings have been reported by Atif et al. (2020), who observed that environmental factors such as temperature and growing conditions significantly influenced garlic growth and morphological characteristics.

Bulb weight was significantly affected by both location and treatment, while the interaction between location and treatment was not significant. The significant location effect indicates that environmental conditions played a major role in bulb development and biomass accumulation. Differences in soil properties, nutrient availability, and climatic conditions among locations likely influenced the production and translocation of assimilates to the bulbs.

The significant treatment effect suggests that the treatments contributed to variations in bulb weight, possibly through improved nutrient uptake, resource utilization, or enhanced plant growth. However, the absence of a significant interaction indicates that treatment performance was relatively consistent across locations, suggesting that the treatments exerted similar effects under different environmental conditions. These findings are consistent with those of Desta et al. (2021), who reported that favourable growth conditions and improved plant performance contribute significantly to increased bulb weight and overall garlic productivity.

Bulb diameter was significantly influenced by location but was not significantly affected by treatment, and no significant interaction between location and treatment was observed. The strong effect of location indicates that environmental conditions were the primary determinants of bulb size. Variations in soil fertility, moisture availability, and climatic conditions among locations likely influenced bulb expansion and development.

Although numerical differences among treatments were observed, these differences were insufficient to produce statistically significant changes in bulb diameter. The absence of a significant interaction further indicates that treatment responses were stable across locations. Similar observations have been reported by Anand et al. (2022), who found that bulb development in garlic is strongly influenced by environmental factors, which often exert a greater effect on bulb size than management interventions.

Conclusion

The study demonstrated that location was the most influential factor affecting garlic growth and yield attributes. Significant differences among locations were observed for plant height, bulb weight, and bulb diameter, indicating that environmental conditions such as soil characteristics, moisture availability, temperature, and local management practices played a major role in determining garlic performance.

Treatment effects varied among the measured parameters. Plant height and bulb diameter were not significantly affected by treatment, suggesting that the treatments did not substantially influence vegetative growth or bulb size. However, bulb weight was significantly affected by treatment, indicating that the treatments contributed to differences in biomass accumulation and bulb development. The significant location $\times$ treatment interaction observed for plant height suggests that treatment responses depended on environmental conditions, whereas the absence of significant interactions for bulb weight and bulb diameter indicates relatively stable treatment performance across locations.

Overall, the findings highlight the importance of site-specific environmental conditions in garlic production. While the evaluated treatments showed limited effects on plant height and bulb diameter, their influence on bulb weight suggests potential benefits for improving yield. Therefore, future garlic production strategies should consider both environmental suitability and appropriate management practices to maximize growth and yield performance across different locations.

References

- Abbey, J. A., Percival, D., Asiedu, S. K., Prithiviraj, B., & Schilder, A. (2019). Biofungicides as alternative to synthetic fungicide control of grey mould (*Botrytis cinerea*): Prospects and challenges. *Biocontrol Science and Technology*, 29(3), 241–262. <https://doi.org/10.1080/09583157.2018.1548574>
- Anand, M., Sankari, A., Kamalkumaran, P. R., & Velmurugan, P. (2022). Studies on the genetic variability, character association and path coefficient analysis in garlic (*Allium sativum* L.). *Electronic Journal of Plant Breeding*, 13(1), 46–53. <https://doi.org/10.37992/2022.1301.006>
- Anjomshoa, A., Jafary, H., Hassandokht, M. R., Taheri, M., & Abdossi, V. (2020). Study on relationship between morphological and physiological traits with resistance to rust fungus (*Puccinia allii*) in Iranian garlic clones. *Advances in Horticultural Science*, 33(4), 543–552. <https://doi.org/10.13128/ahsc>
- Atif, M. J., Amin, B., Ghani, M. I., Ali, M., & Cheng, Z. (2020). Variation in morphological and quality parameters in garlic (*Allium sativum* L.) bulb influenced by different photoperiod, temperature, sowing and harvesting time. *Plants*, 9(2), 155. <https://doi.org/10.3390/plants9020155>
- Belay, A. F., Yimer, Y. M., Amba, M., & Awulia, T. (2024). Management of garlic rust (*Puccinia allii*) using propiconazole fungicide and its economic importance on garlic (*Allium sativum* L.) production in Enebsie Sarmider. *Journal of Agricultural Science and Food Research*, 17(2), 124–140. <https://doi.org/10.5281/zenodo.11408010>
- Desta, B., Tena, N., & Amare, G. (2021). Growth and bulb yield of garlic as influenced by clove size. *Scientifica*, 2021, 7351873. <https://doi.org/10.1155/2021/7351873>
- FAOSTAT. (2023). *Garlic production data – Bhutan*. Food and Agriculture Organization of the United Nations. <https://www.fao.org/faostat/en/#data/QCL>
- Gebreyohannes, G., & Gebreyohannes, M. (2013). Medicinal values of garlic: A review. *International Journal of Medicine and Medical Sciences*, 5(9), 401–408. <https://doi.org/10.5897/IJMMS2013.0960>

- Guest, D., & Grant, B. (1991). The complex action of phosphonates as antifungal agents. *Biological Reviews*, 66(2), 159–187. <https://doi.org/10.1111/j.1469-185X.1991.tb01139.x>
- Hahn, M. (2014). The rising threat of fungicide resistance in plant pathogenic fungi: *Botrytis* as a case study. *Journal of Chemical Biology*, 7(4), 133–141. <https://doi.org/10.1007/s12154-014-0113-1>
- Havlin, J. L., & Schlegel, A. J. (2021). Review of phosphite as a plant nutrient and fungicide. *Soil Systems*, 5(3), Article 52. <https://doi.org/10.3390/soilsystems5030052>
- Koike, S. T., Smith, R. F., Davis, R. M., Nunez, J. J., & Voss, R. E. (2001). Characterization and control of garlic rust in California. *Plant Disease*, 85(6), 585–591. <https://doi.org/10.1094/PDIS.2001.85.6.585>
- Kowata, L. S., Alves, G., Moreira, L. M., & May-De Mio, L. L. (2012). Potassium, calcium and copper phosphite to control peach rust and brown rot. *Idesia*, 30(3), 93–96. <https://doi.org/10.4067/S0718-34292012000300012>
- Mengesha, W., & Tesfaye, A. (2015). Effect of spacing on incidence and severity of garlic rust (*Puccinia allii*) and bulb yield and related traits of garlic at eastern Ethiopia. *Journal of Plant Pathology & Microbiology*, 6(10), Article 314. <https://doi.org/10.4172/2157-7471.1000314>
- Reuveni, R., Reuveni, M., & Agapov, V. (1996). Foliar sprays of NPK fertilizers induce systemic protection against *Puccinia sorghi* and *Exserohilum turcicum* and growth response in maize. *European Journal of Plant Pathology*, 102(4), 339–348. <https://doi.org/10.1007/BF01878128>
- Ribeiro Chagas, J. F., Vêras da Costa, R., Rodrigues dos Santos, G., Abadia Ventura, M. V., & Costa, E. M. (2020). Control de las enfermedades foliares fúngicas y productividad dependiendo de la aplicación de fosfito y fungicida en dos híbridos de maíz. *Biotecnología Vegetal*, 20(1), 33–41.
- Singh, P., Singh, J., Singh, S., & Singh, B. (2014). Medicinal values of garlic (*Allium sativum* L.) in human life: An overview. *Greener Journal of Agricultural Sciences*, 4(6), 265–280. <https://doi.org/10.15580/GJAS.2014.6.031914151>