International Journal of Plant & Soil Science

Volume 38, Issue 6, Page 12-18, 2026; Article no.IJPSS.158838
ISSN: 2320-7035

Influence of Chlormequat Chloride and Maleic Hydrazide on Yield and Yield Components of Rice (*Oryza sativa* L.)

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/ijpss/2026/v38i66097

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://pr.sdiarticle5.com/review-history/158838

Original Research Article

Received: 20/03/2026
Published: 26/05/2026

Abstract

Rice productivity is often affected by climate variability and lodging, especially in coastal regions, leading to yield losses and poor grain quality. Plant growth regulators such as chlormequat chloride and maleic hydrazide are used to modify plant growth and improve assimilate distribution, lodging resistance, and yield performance in rice. A field investigation was carried out on rice during the *rabi*, 2020 - 21 at the wetland farm of S.V. Agricultural College, Tirupati, Andhra Pradesh. The goal was to study the effects of foliar application of maleic hydrazide and chlormequat chloride on rice yield and its attributes. The experiment followed a Randomized Block Design (RBD) with seven treatments and three replications. Twenty one day old rice seedlings were transplanted at two seedlings per hill. The treatments included control (T_1), maleic hydrazide at 5000 ppm (T_2), 10,000 ppm (T_3), and 15,000 ppm (T_4). It also included chlormequat chloride at

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Cite as: *Naidu, K. T., Kumar, A. R. N., Umamahesh, V., & Reddy, P. M. (2026). Influence of Chlormequat Chloride and Maleic Hydrazide on Yield and Yield Components of Rice (Oryza sativa L.). International Journal of Plant & Soil Science, 38(6), 12–18. https://doi.org/10.9734/ijpss/2026/v38i66097*

250 ppm (T_5), 500 ppm (T_6), and 750 ppm (T_7), applied as a foliar spray during the flowering stage. Observations on productive tillers, plant^{-1}, grains panicle^{-1}, filled grains panicle^{-1}, grain yield, straw yield, and test weight were recorded and analysed statistically using ANOVA. Significant differences appeared among the treatments for all studied parameters. Chlormequat chloride at 500 ppm (T_6) showed the highest results for productive tillers plant^{-1} (10.00), grains panicle^{-1}(185.33), filled grains panicle^{-1}(173.66), grain yield (5248 kg ha^{-1}), straw yield (7248 kg ha^{-1}), and test weight (20.66 g). The untreated control had the lowest values for all yield attributes and parameters. The improved performance from growth retardant treatments resulted from better assimilate distribution, higher photosynthetic efficiency, and improved grain filling. The study concluded that foliar application of chlormequat chloride @ 500 ppm is an effective method to boost rice productivity.

Keywords: Chlormequat chloride; maleic hydrazide; growth retardants; grain yield; Rice (Oryza sativa L.), yield attributes.

1. Introduction

India is the second largest producer of rice in the world and one of the largest consumers. Rice holds a prominent position in Indian agriculture both in terms of area under cultivation and total production (Dey *et al.,* 2022). The crop is grown widely in various agro-climatic zones from irrigated plains of Punjab and Haryana to rainfed and coastal ecosystems of eastern and southern India. The major rice growing states of India include West Bengal, Uttar Pradesh, Punjab, Telangana, Andhra Pradesh, Bihar and Tamil Nadu (Government of India, 2023; Food and Agriculture Organization of the United Nations, 2023; Xie et al., 2019). Rice is an important part of the country's economy and culture and provides livelihood to millions of farmers and agricultural workers. It also plays a key role in food security and supports the agricultural economy through processing, milling, marketing and export activities.

Climate change has created a major challenge to agricultural production in India especially in the coastal regions of Andhra Pradesh where agriculture is heavily reliant on seasonal rainfall patterns (IPCC, 2022). Coastal areas are very vulnerable to extreme weather events such as high precipitation, flooding and cyclonic storms during critical stages of crop growth (Krishnan *et al.,* 2020). These climatic disturbances not only affect the crop yield but also have an adverse effect on the soil health, nutrients and overall farming sustainability. The effect of climate change were most evident on seed development, maturation and quality. The cereal crops like rice are often subject to pre-harvest sprouting or premature germination due to excess rainfall and high humidity during maturity stage. Such conditions result in decline in grain quality, seed vigour, poor germination performance and lower storage life. Grains affected by flooding and lodging at maturity are exposed to moisture stress and microbial infection, which reduce seed viability and market value. (Pathak*,* 2023). Also, variation in temperature and moisture during seed filling and maturation interferes with the physiological and biochemical processes associated with seed dormancy and germination. These challenges highlight the need for proper management strategies, such as inducing seed dormancy and using plant growth regulators, to protect seed quality and improve tolerance to climate stress (Copeland and McDonald, 2001; Kashid et al., 2010; Singh et al., 2019).

The increasing problems of climate variability and intensive agriculture have increased the use of plant growth regulators (PGRs) as important tools for sustainable crop management. Plant growth regulators are organic compounds (natural or synthetic) that at low concentrations affect a number of physiological and biochemical processes in plants (Kaur *et al.,* 2015). Maleic hydrazide and chlormequat chloride were selected due to their role as growth retardants that inhibit gibberellin activity and improve assimilate partitioning, leading to enhanced yield (Rademacher, 2000; Taiz *et al.,* 2015). These regulators are widely used in cereals to improve plant architecture, lodging resistance and physiological efficiency (Rajala and Peltonen-Sainio, 2001; Kaur *et al.,* 2015). Hormonal interactions play a key role in determining seed dormancy, and the application of such growth regulators can influence this process (Rajala, 2003). Therefore, the use of maleic hydrazide and chlormequat chloride can be considered a potential approach for managing seed dormancy and reducing pre-harvest sprouting losses in rice.

Therefore, the present study was conducted to assess the effects of maleic hydrazide and chlormequat chloride on rice yield and its component traits, with particular focus on their potential to enhance crop performance and induce seed dormancy under coastal agro-climatic conditions.

2. Material and Methods

The field experiment was carried out in the wetland farm of S.V. Agricultural College, Tirupati, in the Southern Agro-Climatic Zone of Andhra Pradesh, India, during the rabi season of 2020 - 21. The soil had a neutral response and was sandy clay loam. Twenty-one-day-old seedlings were transplanted onto the main field at two seedlings per hill after being raised in a nursery employing line sowing on prepared beds. T_1 - Control, T_2 - Maleic hydrazide @ 5000 ppm, T_3 - Maleic hydrazide @ 10,000 ppm, T_4 - Maleic hydrazide @ 15,000 ppm, T_5 - Chlormequat chloride @ 250 ppm, T_6 - Chlormequat chloride @ 500 ppm and T_7 - Chlormequat chloride @ 750 ppm ppm applied as foliar spray during the flowering stage. To document growth and yield parameters, five plants per treatment were randomly tagged in each replication.

2.1 Number of Productive Tillers Plant^{-1}

At harvest, the number of tillers bearing panicles per plant was recorded and expressed as the number of productive tillers per plant.

2.2 Total Number of Grains Panicle^{-1}

The total number of grains from five panicles was counted, and the mean value was calculated and expressed as the number of grains per panicle.

2.3 Number of Filled Grains Panicle^{-1}

The number of filled grains was determined separately by excluding chaffy and poorly filled grains from the tagged hills in each plot, and the results were expressed as the number of filled grains per panicle.

2.4 Grain Yield (kg ha^{-1})

Grain harvested from the net plot area was thoroughly sun-dried and weighed, and grain yield per hectare was subsequently calculated based on the net plot area.

2.5 Straw Yield (kg ha^{-1})

Straw obtained from the net plot area was thoroughly sun-dried and weighed, and straw yield per hectare was subsequently calculated on the basis of the net plot area.

2.6 Test Weight (1000 Grain Weight)

Thousand filled grains were counted from each treatment and replication and their weight was expressed in grams.

2.7 Statistical Analysis

The study used a Completely Randomized Design (CRD) with three replications to ensure proper experimental control and statistical reliability. The experimental data were subjected to analysis of variance (ANOVA) to assess the significance of treatment effects. Mean separation was performed wherever the ANOVA showed significant differences. We included measures of variability, such as standard errors and critical difference (CD) values, to improve the transparency, strength, and reproducibility of the findings.

3. Results and Discussion

3.1 Number of Productive Tillers Plant^{-1}

The analysis of the data showed that the number of productive tillers plant^{-1} with treatments differed significantly from the control when growth-regulating drugs were applied topically. The treatment chlormequat chloride @ 500 ppm (T_6) (10.00) had more productive tillers per plant, followed by maleic hydrazide @ 5000 ppm (T_2) (9.33) while control (T_1) recorded fewer (6.66) (Table 1).

Application of growth retardants reduced plant height during the tillering stage, which likely decreased apical dominance and promoted better redistribution of photoassimilates towards tiller development. This enhanced assimilate partitioning may have contributed to the production of a higher number of productive tillers compared to the control (Rademacher, 2000). Similar findings were reported by Singh et al. (2019) in rice, where the application of plant growth regulators significantly increased the number of productive tillers over untreated plants.

3.2 Number of Grains Panicle^{-1}

Significant variation was observed among treatments with respect to number of grains panicle^{-1}. The control (T_1) exhibited the lowest grains panicle^{-1} (125.66). It was followed by maleic hydrazide applied at 10,000 ppm (T_3) and 15,000 ppm (T_4), which were statistically similar, recording 132.66 and 141.33 grains panicle^{-1}, respectively. Treatments comprising chlormequat chloride at 250 ppm (T_5) and 750 ppm (T_7), along with maleic hydrazide at 5000 ppm (T_2), were at par, registering 174.66, 176.00, and 182.00 grains panicle^{-1}, respectively. The maximum grains panicle^{-1} (185.33) was obtained with chlormequat chloride at 500 ppm (T_6) (Table 1).

The increase in grains panicle^{-1} under plant growth regulator (PGR) application is mainly due to reduced vegetative growth and improved allocation of assimilates towards reproductive sinks. Growth retardants such as chlormequat chloride act by inhibiting gibberellin biosynthesis, which restricts excessive shoot elongation and promotes a favourable source-sink balance, ultimately enhancing yield components (Rademacher, 2000). Similar increase in grain panicle-^{1} through better assimilate partitioning and sink strength in rice has been reported by Singh et al. (2019), Parvathi *et al.* (2025) and Ashraf *et al.* (2025).

3.3 Number of Filled Grains Panicle^{-1}

The number of filled grains panicle^{-1} varied significantly among the different treatments imposed. Among all the treatments, application of chlormequat chloride @ 500 ppm (T_6) produced the highest number of filled grains panicle^{-1} (173.66). This was followed by maleic hydrazide @ 5000 ppm (T_2) with 170.67 filled grains panicle^{-1}. The untreated control (T_1) registered the minimum number of filled grains panicle^{-1} (112.66) (Table 1).

Using growth retardants like chlormequat chloride and maleic hydrazide can improve yield attributes in rice and other cereals. They help reduce excessive vegetative growth, improve nutrient distribution, and increase resistance to lodging (Rajala, 2003; Pirasteh-anosheh *et al.,* 2016). Study by Xie *et al.* (2019) showed that applying chlormequat chloride significantly increased the number of filled grains panicle^{-1}, panicle density, and grain yield by enhancing physiological efficiency and promoting the movement of photosynthates to developing reproductive areas. Niu *et al.* (2022) found that growth retardants strengthen culms, decrease lodging, and improve grain filling and productive spikelets in cereals. Ma *et al.* (2026) explained that gibberellin biosynthesis inhibitors like chlormequat chloride help regulate hormone levels and the distribution of nutrients, leading to better reproductive development and more filled grains panicle^{-1} in cereals.

3.4 Grain Yield (kg ha^{-1})

Grain yield is considered one of the most important yield attributes and is largely influenced by the accumulation and partitioning of dry matter during the post-anthesis period. Analysis of variance revealed significant differences among the treatments with respect to grain yield. Among the various treatments, application of chlormequat chloride @ 500 ppm (T_6) recorded the highest grain yield (5248 kg ha^{-1}). This was followed by maleic hydrazide @ 5000 ppm (T_2), which produced a grain yield of 5072 kg ha^{-1} In contrast, the untreated control (T_1) registered the lowest grain yield of 2319 kg ha^{-1} at harvest (Table 1).

Enhanced grain yield under growth retardant treatments may be attributed to improved photosynthetic efficiency, higher chlorophyll retention and delayed senescence during later growth stages, leading to better production and utilization of photoassimilates. Efficient transfer of stored nutrients from the stem to developing grains during grain filling helps improve yield. Growth retardants also enhance dry matter accumulation, tiller production, sink strength and overall yield performance (Rademacher, 2000; Rajala and Peltonen-Sainio, 2001). Chlormequat chloride has been reported to influence hormonal balance and maintain physiological activity, thereby improving yield (Taiz *et al.,* 2015). Similar findings of enhanced photosynthetic efficiency, assimilate partitioning and grain yield due to chlormequat chloride application were reported by Li *et al.* (2025) and Ma *et al.* (2026). The present results are also in agreement with earlier studies by Hunje *et al.* (1995) in cowpea and Singh et al. (2019) in rice.

3.5 Straw Yield (kg ha^{-1})

The data on straw yield showed considerable differences among the treatments. Among the different treatments, chlormequat chloride @ 500 ppm (T_6) produced the highest straw yield (7248 kg ha^{-1}), whereas the untreated control (T_1) recorded the lowest straw yield of 5371 kg ha^{-1} (Table 1).

The increase in straw yield under growth retardant treatments may be attributed to enhanced vegetative growth, higher dry matter accumulation and sustained leaf area duration, leading to greater biomass production. Growth retardants such as chlormequat chloride improve canopy architecture, stem strength and nutrient use efficiency, thereby promoting better accumulation of vegetative biomass (Rademacher, 2000; Rajala and Peltonen-Sainio, 2001).

The straw yield has improved through assimilate partitioning and physiological efficiency under chlormequat chloride application, as reported by Li *et al.* (2025), while gibberellin biosynthesis inhibitors are known to regulate plant architecture and biomass accumulation in cereals (Ma *et al.,* 2026). The present findings are in agreement with earlier reports by Afria *et al.* (1998) in guar and Mehriya and Khangarot (2000) in mustard.

Table 1. Influence of chlormequat chloride and maleic hydrazide on yield parameters in rice

S.No.	Treatments	Productive tillers plant^{-1}	Grains panicle^{-1}	Filled grains panicle^{-1}	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Test weight (g)
1	T_1: Control	6.66	125.66	112.66	2,319	5,371	13.08
2	T_2: Maleic hydrazide @ 5000ppm	9.33	182.00	173.66	5,072	6,520	20.54
3	T_3: Maleic hydrazide @ 10,000ppm	7.33	132.66	121.33	2,816	5,915	14.31
4	T_4: Maleic hydrazide @ 15,000ppm	7.66	141.33	131.00	3,964	6,612	14.96
5	T_5: Chlormequat chloride @ 250ppm	8.00	174.66	130.66	3,421	5,452	15.26
6	T_6: Chlormequat chloride @ 500ppm	10.00	185.33	170.67	5,248	7,248	20.66
7	T_7: Chlormequat chloride @ 750ppm	8.66	176.00	168.00	4,816	6,783	15.21
	CD (p=0.05)	0.96	20.52	18.18	497.79	1132.10	1.96
	SE(m)±	0.32	6.84	6.06	165.93	377.45	0.64

3.6 Test Weight (g)

The influence of foliar application of growth regulating chemicals on test weight revealed significant differences among the treatments. Among the various treatments, chlormequat chloride @ 500 ppm (T_6) recorded the highest test weight (20.66 g), which was statistically comparable to maleic hydrazide @ 5000 ppm (T_2), which recorded 20.54 g. The lowest test weight was observed in the untreated control (T_1) with 13.08 g (Table 1).

The increase in test weight under growth retardant treatments may be due to better movement and use of photosynthates towards developing grains, leading to improved grain filling and seed development.Reduction in plant height caused by growth retardants decreases the distance between source and sink, thereby improving assimilate translocation efficiency and utilization (Kashid *et al.,* 2010). Ma *et al.* (2026) stated that gibberellin biosynthesis inhibitors such as chlormequat chloride improve grain development and seed weight by regulating hormonal balance and promoting efficient mobilization of assimilates during grain filling.

4. Conclusion

The present investigation revealed that foliar application of growth regulators significantly influenced rice yield and yield-contributing characters. Among the treatments, chlormequat chloride proved more effective than the untreated control in enhancing productive tillers plant^{-1}, grains panicle^{-1}, filled grains panicle^{-1}, grain yield, straw yield, and test weight. In particular, chlormequat chloride @ 500 ppm exhibited superior performance by improving yield attributes and overall productivity of rice. The beneficial effects of growth retardants may be attributed to improved assimilate partitioning, enhanced photosynthetic efficiency, better translocation of photosynthates, and reduced excessive vegetative growth. Therefore, foliar application of chlormequat chloride

@ 500 ppm can be considered a promising management practice for improving yield and yield attributes in rice under wetland conditions.

Disclaimer (Artificial Intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during writing or editing of this manuscript.

Competing Interests

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

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Peer-review history:
The peer review history for this paper can be accessed here:
https://pr.sdiarticle5.com/review-history/158838