



Effect of Nano Encapsulated Pendimethalin on Growth Attributes of Rice

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Authors' contributions

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

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ABSTRACT

Weed infestation is a major problem in upland rice of Kerala. Pendimethalin is a selective pre-emergent herbicide used to control broad-leaved and grassy weeds in rice fields. However, herbicides like pendimethalin often face losses in the agroecosystem through various pathways, reducing their effectiveness and potentially contaminating the environment, including groundwater. Encapsulation of herbicides is an innovative method designed to enhance their efficacy while minimizing environmental contamination, making herbicide application more efficient for weed control. A field experiment was carried out at the Instructional Farm, College of Agriculture,

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Vellayani, Kerala, India to evaluate the effect of different concentrations of Nano Encapsulated Pendimethalin (NEP) for weed management in upland rice. Synthesis of nano encapsulated pendimethalin was done at Department of Agronomy, College of Agriculture, Vellayani. The study revealed that nano encapsulated pendimethalin had significant influence on growth attributes over normal commercial formulations. Among all the growth parameters Nano Encapsulated Pendimethalin (NEP) with 4% starch aqueous phase at 1.0 kg ha⁻¹ showed comparable result with hand weeding at 15 and 30 Days After Sowing (DAS). The nano encapsulated formulation had a particle size of 486.6 nm and zeta potential of -18 mV.

Keywords: Pendimethalin; nano encapsulation; plant height; leaf area index.

1. INTRODUCTION

“Rice (*Oryza sativa* L.) is one of the most important staple food crops in the world and it occupies a pivotal position in the food security system in India. Uncontrolled weed infestation in upland rice accounts for 42%–100% yield reductions” (Kolo et al. 2021). “Pendimethalin is a selective pre-emergent herbicide used to control broad leaved and grassy weed species in rice. However, the applied herbicides undergo losses in the agroecosystem in different ways (chemical degradation, microbial decomposition, photo-degradation, leaching, run-off, and volatilization), thus lowering the herbicidal action coupled with contaminating ecosystem and groundwater” (Dhanda et al. 2024, Imig et al. 2023). “Encapsulation of herbicides is an innovative approach that addresses issues associated with the application of herbicides for controlling weeds. Further, encapsulation lowers the application rate of herbicides, which in turn reduces the residue carryover of herbicide in soil and minimizes the environmental hazards. Therefore, encapsulated herbicide formulation has greater significance in the future weed management and will become ground-breaking technology in the chemical era of weed control. Herbicide encapsulation is a versatile technology performed at nano and micro-scale by incorporating active ingredients into the suitable carrier. Nano encapsulation of pendimethalin with natural polymers like starch helps in slow and safe release of the herbicide into soil in required concentration thereby controlling its indiscriminate use and aids in season long weed control” (Marimuthu et al. 2022). Nanotechnology opens a door for safe & efficient delivery of active ingredient, improved solubility, reduced environmental impact while maintaining bioactivity and prolonged release in soil. Nano herbicide through its rapid penetration ability kills the weed before it could develop resistance against the herbicide (Manjunatha et al. 2016).

2. MATERIALS AND METHODS

The field experiment was carried out at the Instructional Farm, College of Agriculture, Vellayani, Kerala, India. The farm is located at a latitude of 8°42'85" N and longitude of 76°98'74" E at an altitude of 29 m above MSL. The chosen variety of rice for the study was a short duration variety KAU Manuratna. Synthesis of nano encapsulated pendimethalin was carried out at College of Agriculture Vellayani. The characterization studies were conducted at CSIR-NIIST, Thiruvananthapuram.

2.1 Synthesis and Characterization of Nano Encapsulated Pendimethalin

Pendimethalin 1 mg was dispersed in 4 ml of acetone solvent and sonicated with energy output 25 W under continuous mode for 90 seconds. Poly ethylene glycol polymer of 20 mg was dissolved in 8 ml of dichloromethane solvent and sonicated with energy output 25 W under continuous mode for 90 seconds. Both were mixed well to form organic phase. Took 4 ml of starch polymer with different concentrations (4 and 6 per cent) and stirred with a magnetic stirrer for one hour for the preparation of aqueous phase. The organic phase containing the polymer with herbicide was added drop wise to aqueous phase containing the different starch concentrations to form oil in water phase. It was sonicated with energy output of 25 W under continuous mode for 90s. Then formed oil in water phase was stirred overnight in a magnetic stirrer under room temperature. The nanoparticles produced were collected by centrifugation with 5000 rpm for 15 min under room temperature and dried in vacuum desiccators. The dried particles were collected and stored in vial (Kumar and Chinnamuthu 2017).

2.1.1 Zeta Potential (Z.P)

Using Zetasizer Nano ZS, Malvern equipment, dynamic light scattering (DLS) the mean zeta

potential, electrophoretic mobility and conductivity of nanoparticles were measured at 25°C and at a scattering angle of 90°. Here, one ml of nano encapsulated pendimethalin nanoparticles were dispersed in 200 ml of distilled water containing 1% acetone followed by sonication for 60 min. The samples were kept cold by an external ice bath during sonication process.

2.1.2 Particle size distribution

The average hydrodynamic diameter, size distribution and polydispersity index (PDI) of nanoparticles were measured using a Particle Size Analyzer (Brookhaven, NY, USA) at 25°C and scattering angle of 90°. Sample was prepared by dispersing one ml in 200 ml of distilled water containing 1% acetone followed by 60 min sonication in an ice bath. Particle size was determined based on laser beam scattering technique.

2.1.3 Fourier- transform infrared (FT-IR) spectroscopy

FT-IR spectra were recorded using a PerkinElmer Spectrum IR Version 10.6.0 through attenuated total reflectance (ATR) using 4 cm⁻¹ resolution and 32 scans per spectrum in the range of 500-4000 cm⁻¹. For taking the spectrum, sample was placed on the diamond crystal and gripper plate was placed on the sample to ensure required contact between crystal and sample. The measurement was taken 16 times for each trial and their average was taken.

2.2 Growth Attributes of Rice

Plant height and leaf area index were recorded at 30 DAS, 45 DAS and 60 DAS. Number of tillers m⁻² was recorded at 30 DAS and 45 DAS.

2.3 Treatment Details

There were nine treatments replicated thrice. Different treatments included T₁(NEP with 4% starch aqueous phase 0.5 kg ha⁻¹), T₂(NEP with 4% starch aqueous phase 0.75 kg ha⁻¹), T₃(NEP with 4% starch aqueous phase 1.0 kg ha⁻¹), T₄(NEP with 6% starch aqueous phase 0.5 kg ha⁻¹), T₅(NEP with 6% starch aqueous phase 0.75 kg ha⁻¹), T₆(NEP with 6% starch aqueous phase 1.0 kg ha⁻¹), T₇(Pendimethalin 1.0 kg ha⁻¹), T₈(Hand weeding (HW) at 15 and 30 DAS), T₉(Weedy check). Here NEP stands for nano encapsulated pendimethalin. The statistical

design employed for the study was randomized complete block design.

3. RESULTS

3.1 Characterization Studies

The particle size analysis of the sample revealed an average size of 486.6 nm for NEP with 4% starch aqueous phase 1.0 kg ha⁻¹. Zeta potential data showed incipient stability range for NEP with 4% starch aqueous phase 1.0 kg ha⁻¹ (-18 mV). FTIR results showed a peak at 3339.67 cm⁻¹. This peak was in the region where N-H stretching was observed, which corresponded to the secondary amine group present in pendimethalin. It showed another peak at 1635.21 cm⁻¹ and was consistent with aromatic C=C stretching, which fits pendimethalin's structure since it had aromatic rings. Another peak was observed at 3339.67 cm⁻¹, which corresponded to the O-H stretching vibration, which was present in starch due to the hydroxyl groups involved in hydrogen bonding. Also, it indicated the presence of polyethylene glycol.

3.2 Weed Dry Weight

There were significant variations among treatments with respect to total dry weight of weeds at 30 DAS and 45 DAS. At 30 DAS lower weed dry weight was observed in T₃ (10.54 g) which was on par with T₆ (11.32 g) and T₈ (12.42 g). At 45 DAS the lowest weed dry weight was observed in T₈ (13.78 g) followed by T₃ (32.50 g) and T₆ (35.10 g). At both the intervals T₉ recorded the highest weed dry matter production (35.10 g and 110.26 g respectively).

3.3 Growth Attributes

Plant height of rice depicted significant variation among treatments at 30 DAS, 45 DAS and 60 DAS (Fig. 1). At 30 DAS (58.21 cm), 45 DAS (78.21) and 60 DAS (83.38) taller plants were observed in hand weeding at 15 and 30 DAS (T₈) which was followed by T₃ i.e., NEP with 4% starch aqueous phase 1.0 kg ha⁻¹ (52.03 cm, 72.03 cm and 77.12 cm, respectively). Among all treatments the shortest plants were observed in weedy check at 30 DAS (32.40 cm), 45 DAS (52.40 cm) and 60 DAS (57.48 cm), respectively.

There were significant variations among treatments with respect to number of tillers m⁻² at 30 DAS and 45 DAS (Fig. 2). At 30 DAS higher number of tillers m⁻² (409.33) were observed in

HW twice which was on par with T₃ (406.67) and T₆ (401.33). At 45 DAS, maximum number of tillers m⁻² (460.00) was observed in T₃ which was on par with T₈ (442.67). At 30 DAS and 45 DAS, minimum number of tillers m⁻² (309.33 and 325.33) was recorded in weedy check (T₉).

With respect to total dry matter production Hand weeding twice recorded higher dry matter production (7041.24 kg ha⁻¹) and was comparable with T₃ (6425.01 kg ha⁻¹) (Fig. 3). The lowest was observed in weedy check (3696.13 kg ha⁻¹).

Significant variation was noticed in Leaf Area Index (LAI) at 30 DAS, 45 DAS and 60 DAS (Fig.

4). Higher leaf area index was shown by T₃ at 30 DAS (3.22), 45 DAS (4.11) and 60 DAS (4.23).

4. DISCUSSION

Effective weed control created a favorable environment for crop growth by improving the availability of moisture, nutrients, and sunlight. This, in turn, indirectly increased the total chlorophyll content and photosynthetic rate, leading to higher carbohydrate accumulation (Gummadi and Kumari 2022, Alptekin et al. 2023). Increased photosynthesis directly correlates with higher carbohydrate levels, which are vital for crop yield and energy storage (Lowry and Smith 2018). As a result, there was an

Table 1. Effect of nano encapsulated pendimethalin on weed dry weight

Treatments	Weed dry weight (g)	
	30 DAS	45 DAS
T ₁ –NEP with 4% starch aqueous phase 0.5 kg ha ⁻¹	19.70	54.93
T ₂ – NEP with 4% starch aqueous phase 0.75 kg ha ⁻¹	17.89	47.20
T ₃ – NEP with 4% starch aqueous phase 1.0 kg ha ⁻¹	10.54	32.50
T ₄ – NEP with 6% starch aqueous phase 0.5 kg ha ⁻¹	22.72	61.66
T ₅ - NEP with 6% starch aqueous phase 0.75 kg ha ⁻¹	20.16	58.20
T ₆ - NEP with 6% starch aqueous phase 1.0 kg ha ⁻¹	11.32	35.10
T ₇ - Pendimethalin 1.0 kg ha ⁻¹	21.20	52.53
T ₈ - Hand weeding at 15 and 30 DAS	12.42	13.78
T ₉ -Weedy check	63.53	110.26
SEm(±)	1.469	23.76
CD(P=0.05)	4.405	8.437

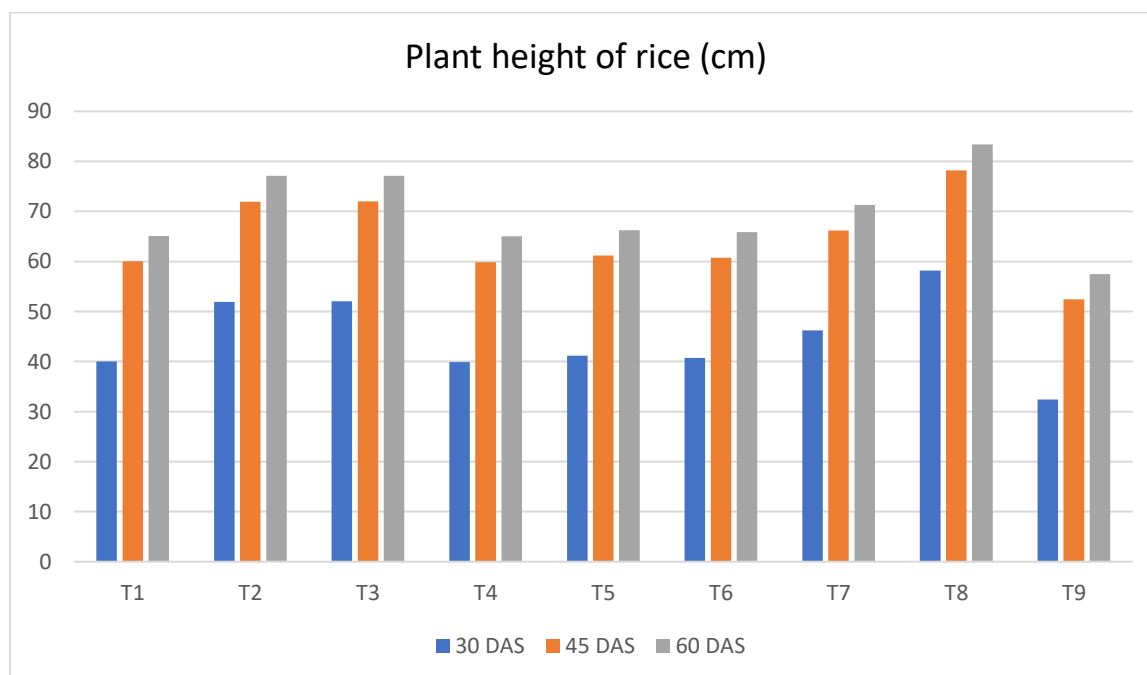


Fig. 1. Effect of nano encapsulated pendimethalin on plant height of rice (cm) at 30 DAS, 45 DAS and 60 DAS

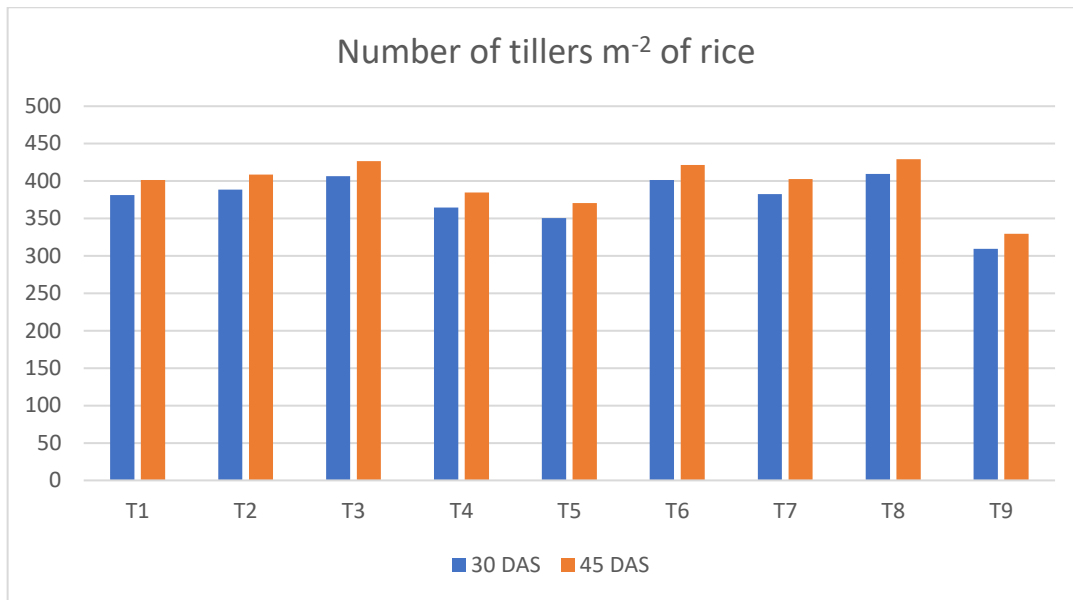


Fig. 2. Effect of nano encapsulated pendimethalin on number of tillers m⁻² of rice

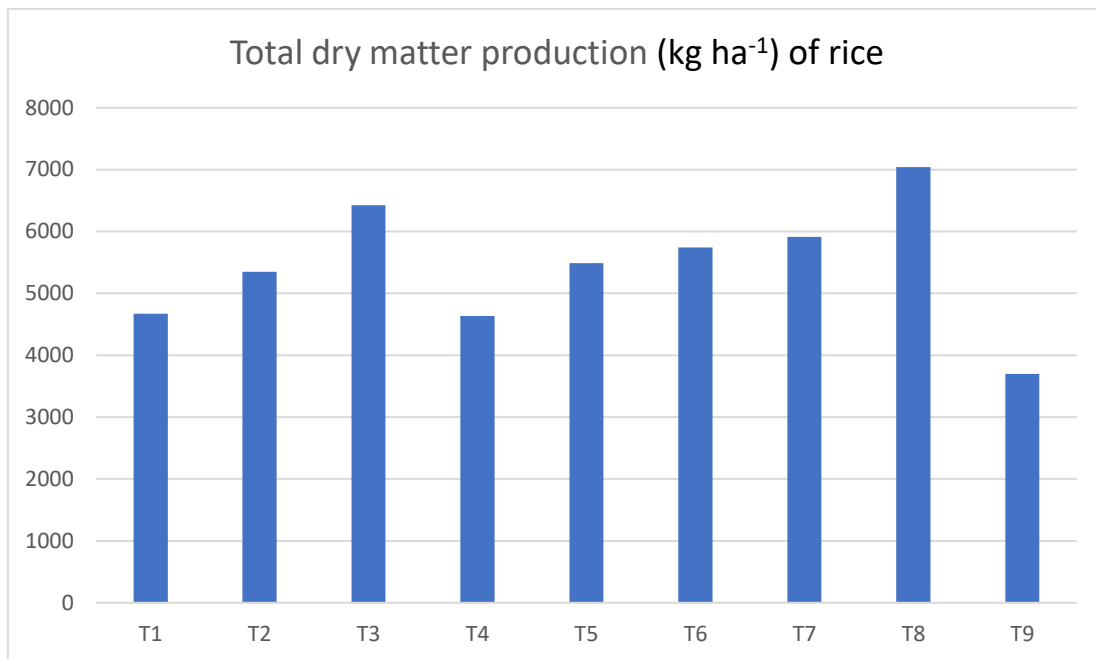


Fig. 3. Effect of Nano Encapsulated Pendimethalin on total dry matter production of rice (kg ha⁻¹)

increase in the number of tillers per meter square, leaf area index, and total dry matter production in rice (Raj and Syriac 2018). The crops competed with weeds for the resources available, which led to inadequacy of nutrients resulted in reduced dry matter accumulation of crop (Vimalrajiv et al. 2019). These results were in accordance with the findings of Vimalrajiv *et al.* (2018). Effective weed control through slow release of nano formulation likely created a more favorable environment for

plant growth, enabling improved nutrient uptake. These results were in accordance with the findings of Bommayasamy and Chinnamuthu (2021), who observed an increased number of tillers m⁻², longer panicles, heavier panicles, and a higher number of filled grains per panicle with oxadiargyl-entrapped zeolite and oxadiargyl-entrapped biochar. Encapsulating herbicides led to enhanced weed control, which in turn facilitated better nutrient uptake by the crop.

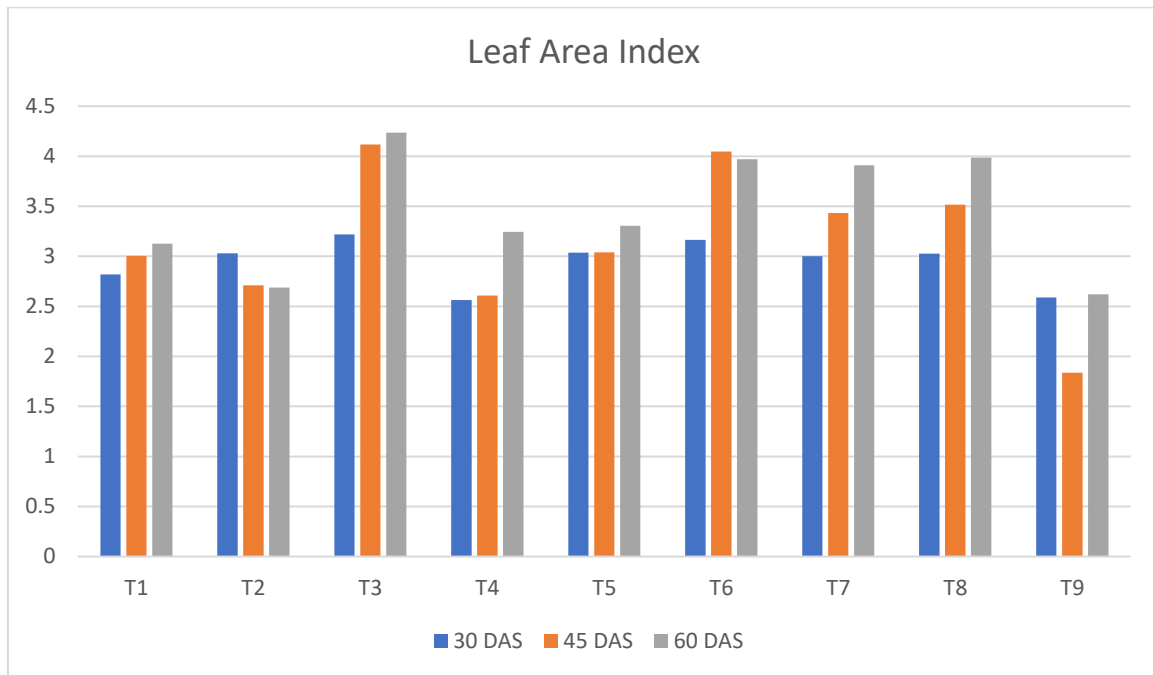


Fig. 4. Effect of Nano Encapsulated Pendimethalin on leaf area index of rice

5. CONCLUSION

Among all the weed management treatments, Hand weeding at 15 DAS and 30 DAS showed significantly higher growth attributes which was comparable with NEP with 4% starch aqueous phase 1.0 kg ha^{-1} . In case of weed dry weight at 30 and 45 DAS NEP with 4% starch aqueous phase 1.0 kg ha^{-1} significant effect over other treatments. Nano encapsulated formulation of pendimethalin exhibited higher bio efficacy on weeds and depicted significant influence on growth attributes over normal commercial formulations.

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 no competing interests exist.

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