



RESEARCH ARTICLE

Management of *Pistia stratiotes* L. in the rice ecosystem

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Abstract

Pistia stratiotes L. (commonly known as water lettuce), a free-floating, stoloniferous aquatic macrophyte belonging to the family Araceae, has recently emerged as one of the world's most problematic aquatic weeds. A pot culture experiment evaluated the efficacy of various herbicidal and eco-friendly chemicals against *Pistia* in completely randomised design (CRD) with 11 treatments replicated thrice. The treatments comprised glufosinate ammonium (0.50 kg ha⁻¹), carfentrazone-ethyl (0.02 kg ha⁻¹), 2,4-D Na salt (0.8 kg ha⁻¹), bispyribac-sodium (0.025 kg ha⁻¹), chlorimuron-ethyl + metsulfuron-methyl (0.004 kg ha⁻¹), chlorimuron-ethyl + metsulfuron-methyl combined with carfentrazone-ethyl (0.004 + 0.02 kg ha⁻¹) and alternative chemicals including sodium chloride (5 %), acetic acid (5 %), lime (0.1 kg m⁻²), gypsum (0.1 kg m⁻²), along with an untreated control. Observations on phytotoxicity, regrowth and biomass (fresh weight) at 20 days after spraying (DASP) revealed that carfentrazone-ethyl, glufosinate ammonium and a combination of carfentrazone-ethyl with chlorimuron + metsulfuron were effective in suppressing *Pistia* with 80 % drying or bleaching by 6 DASP. No regrowth of *Pistia* was observed by 20 DASP in these herbicides treated pots. Acetic acid induced rapid phytotoxicity, resulting in complete bleaching on the day of application. However, sodium chloride, lime and gypsum were ineffective in suppressing growth of *Pistia*. The most effective treatments were further evaluated in rice with *Pistia* to assess crop safety. Acetic acid and glufosinate ammonium caused significant crop injury to rice, while carfentrazone-ethyl demonstrated high efficacy against *Pistia* with no adverse effects on rice. The results identify carfentrazone-ethyl at 0.02 kg ha⁻¹ as a fast-acting, selective and environmentally safer option for managing *Pistia* in flood-prone lowland rice ecosystems.

Keywords: aquatic weeds; carfentrazone-ethyl; management; *Pistia stratiotes*; rice ecosystem

Introduction

Pistia stratiotes L. (common name: water lettuce; family: Araceae) is a perennial, free-floating aquatic macrophyte characterised by a stemless, stoloniferous growth habit and fibrous roots. It is extremely fast growing and primarily reproduces asexually via stolons (runners) that form daughter plants but can also produce seeds. It is recognised as one of the world's most problematic aquatic weeds (1) and is widely distributed across tropical and subtropical water bodies (2). Owing to its severe adverse impacts on biodiversity and aquatic ecosystems, *P. stratiotes* has been listed as an invasive species in the global invasive species database (3, 4). Dense mats of *Pistia* clog waterways, reduce light penetration and impair gaseous exchange at the air-water interface, resulting in reduced dissolved oxygen levels and deterioration of water quality. In India, the widespread occurrence of *Pistia* in ponds, irrigation canals, reservoirs and wetlands has been documented (5).

In recent years, aquatic weeds such as *P. stratiotes* and *Salvinia molesta* have emerged as serious weeds in rice ecosystems as they are highly invasive and free-floating known for forming dense, light-blocking mats. A study conducted to identify invasive alien plant species in flood-affected areas of Alappuzha district revealed that *Pistia* had invaded wetlands in all 17 villages surveyed and was categorised as a high-risk species based on its management

difficulty (6). The extend of invasion of *Pistia* that enters the rice fields during flash floods in Pokkali ecosystem of Kerala is illustrated in Fig. 1. The rapid growth and high resilience of *Pistia* contribute to its persistence as an invasive species. Given its aquatic habitat, management strategies should minimise the risk of secondary pollution associated with chemical control measures. Therefore, there is a critical need to develop more efficient, eco-friendly and cost-effective management approaches. However, several chemical and eco-friendly approaches have been reported to offer potential for the control of aquatic weeds, including *Pistia*. In this context, the present study was undertaken to evaluate the efficacy of selected herbicides and eco-friendly methods for the management of *Pistia*.



Fig. 1. Extend of invasion of *Pistia* in rice fields during flash floods in Pokkali ecosystem of Kerala.

Materials and Methods

The experiment was conducted at the Rice Research Station, Vyttila, Kerala, India (9.9667° N latitude, 76.3168° E longitude), situated at an altitude of approximately 1 m above mean sea level. The study comprised of two pot culture experiments undertaken during December 2023 to February 2024 to evaluate the efficacy of selected herbicides and other eco-friendly chemicals against *Pistia* and their safety to rice. The period of study experienced maximum temperature of 33.5 °C and minimum temperature of 21.1 °C and had an average evapotranspiration of 3 mm day⁻¹. The first experiment was laid out in a completely randomised design (CRD) with 11 treatments, each replicated 3 times. The treatments included T₁- glufosinate ammonium at 0.50 kg ha⁻¹ (sweep power 13.5 SL), T₂- carfentrazone-ethyl at 0.02 kg ha⁻¹ (affinity 40 DF), T₃-2,4-D (Na salt) at 0.8 kg ha⁻¹ (fermoxone 80 WP), T₄- bispyribac sodium at 0.025 kg ha⁻¹ (adora 10 SC), T₅-chlorimuron-ethyl + metsulfuron-methyl at 0.004 kg ha⁻¹ (almix 20 WP), T₆- chlorimuron-ethyl + metsulfuron-methyl + carfentrazone-ethyl (0.004 + 0.02 kg ha⁻¹), T₇- sodium chloride (5 %), T₈- acetic acid (5 %), T₉- lime (calcium carbonate) at 0.1 kg m⁻², T₁₀- gypsum (calcium sulphate) at 0.1 kg m⁻² and T₁₁-a non-sprayed control.

Plastic pots of 40 cm diameter having 20 L capacity were filled with 15 L of water along with 100 g of dry cow dung making it nutrient rich that favours early establishment of *Pistia*. Uniform quantity of *P. stratiotes* (100 g fresh weight per pot) was introduced and allowed to establish for 5 days. Treatments were applied using a hand sprayer at a spray volume 1 L per pot directly onto the leaf surface of the floating weed without draining the water. Visual injury symptoms were assessed using a zero to 10 toxicity scale with zero for no injury and 10 for complete mortality (7) and observations recorded at 1, 2, 4, 6, 10 and 20 days after spraying (DASP). The scores were converted to percentage injury by multiplying the numerical ratings by 10. Regrowth of *Pistia* was assessed at 20 DASP, by recording the fresh and dry biomass of the weed. Weed control efficiency (WCE) was calculated following the standard formula (8) and expressed as percentage.

The most effective chemicals identified from experiment I were further assessed for crop safety in rice under pot conditions in experiment II. For this, rice seedlings were transplanted in pots and 20 days later, *Pistia* was introduced at 100 g per pot. After five days of weed establishment, four selected treatments from first study viz, T₁, T₂, T₆ and T₈ were applied using a hand sprayer at a spray volume of

300 L per ha directly onto the leaf surface of both crop and weed without draining water. Crop phytotoxicity symptoms and weed regrowth were recorded following the same methodology adopted in experiment I. The experimental data were subjected to analysis of variance (ANOVA) using the statistical software WASP 2.0 (9). Treatment means were compared using critical difference obtained from ANOVA at 5 % level of significance.

Results

Effect of herbicides and alternative chemicals on phytotoxicity of *Pistia*

The response of *Pistia* to the herbicides and other chemicals tested showed significant variation (Fig. 2). Application of 5 % acetic acid (T₈) resulted in immediate phytotoxicity with 80 % bleaching on the day of spraying. Among the herbicides, carfentrazone-ethyl (T₂) induced rapid phytotoxic symptoms, with yellowing and necrosis evident by the second day, progressing to approximately 80 % yellowing and drying by 6 DASP. Glufosinate ammonium (T₁), a contact herbicide, initially caused yellowing and necrosis confined to the leaf margins on the second day, but resulted in about 90 % drying by 6 DASP.

The combination of carfentrazone-ethyl with chlorimuron-ethyl + metsulfuron-methyl (T₆) also showed 80 % control of *Pistia* by 6 DASP. In contrast, chlorimuron-ethyl + metsulfuron-methyl alone (T₅) did not provide effective control initially, although phytotoxicity increased to 80 % by 10 DASP, indicating that the efficacy of T₆ was primarily attributable to carfentrazone-ethyl. The auxin herbicide 2,4-D (T₃) showed limited effectiveness, achieving only 50 % phytotoxicity at 6 DASP. Bispyribac sodium (T₄) caused 60 and 70 % leaf yellowing by 6 and 20 DASP, respectively, without leading to tissue decay or drying.

Non-herbicidal treatments including 5 % sodium chloride, lime and gypsum, did not exhibit any weed control effect though sodium chloride could induce plant dehydration and lime and gypsum could influence soil pH and nutrient uptake, affecting plant growth. The progression of phytotoxicity from 2 to 20 DASP is depicted in Fig. 1. Carfentrazone-ethyl, glufosinate ammonium and the combination of carfentrazone-ethyl with chlorimuron-ethyl + metsulfuron-methyl effectively suppressed *Pistia* by 6 DASP, resulting in complete bleaching or drying. No regrowth of *Pistia* was observed in herbicide-treated pots up to 20 DASP.

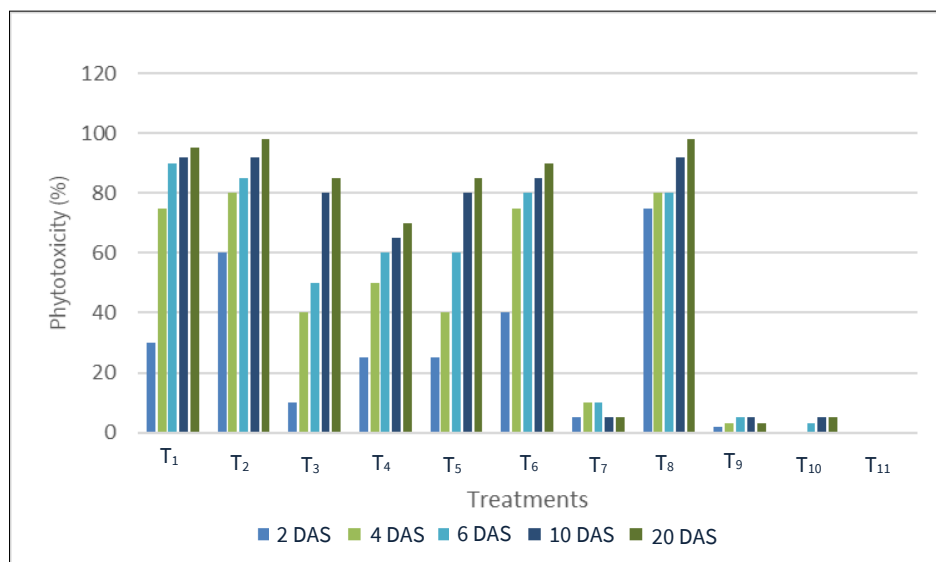


Fig. 2. Effect of treatments on phytotoxicity of *Pistia* (%).

Effect of herbicides and alternative chemicals on biomass of *Pistia* and weed control efficiency

The fresh biomass of *Pistia* recorded at 20 DASP ranged from 3.8 to 560.3 g per pot, indicating a significant effect of treatments on weed growth (Table 1). Among the herbicides, glufosinate ammonium (T₁) recorded the lowest biomass (4.17 g per pot), which was statistically comparable with carfentrazone-ethyl (T₂; 7.3 g per pot), carfentrazone-ethyl + chlorimuron-ethyl + metsulfuron-methyl (T₆; 17.1 g per pot), 2,4-D (T₃; 24.9 g per pot) and chlorimuron-ethyl + metsulfuron-methyl (T₅; 28.1 g per pot). Acetic acid (T₈) resulted in the minimum biomass at 20 DASP, indicating complete suppression of *Pistia* growth.

In contrast, treatments T₇ (sodium chloride, 524.4 g per pot), T₉ (lime, 548.8 g per pot) and T₁₀ (gypsum, 566.5 g per pot) were on par with the untreated control (560.3 g per pot), indicating negligible effect on *Pistia* growth. In these treatments, *Pistia* biomass increased approximately five-fold over the initial weight, like the control.

The WCE values corroborated the biomass data (Table 1). Except for bispyribac sodium (T₄), all herbicide treatments recorded WCE > 90 %, with T₁, T₂, T₆ and T₈ exhibiting WCE exceeding 95 %, indicating their superior efficacy in controlling *Pistia*.

Effect of treatments in rice + *Pistia* system

The efficacy of the four most promising treatments viz., T₁, T₂, T₆ and T₈ was further evaluated in a rice + *Pistia* system. Application of acetic acid (5 %) caused immediate phytotoxicity, resulting in complete bleaching of *Pistia* on the day of spraying; however, it also induced severe crop injury, with approximately 50 % phytotoxicity in rice plants. Similarly, glufosinate ammonium (T₁) caused yellowing and drying of *Pistia* but also resulted in about 50 % phytotoxicity in rice by 2 DASP, rendering it unsuitable for use in the rice + *Pistia* system.

Among the herbicidal treatments, carfentrazone-ethyl (T₂) exhibited rapid phytotoxic effects on *Pistia*, characterised by yellowing and drying by 2 DASP and achieved complete control by 20 DASP without causing any adverse effects on rice. The combination of carfentrazone-ethyl with chlorimuron-ethyl + metsulfuron-methyl (T₆) showed a response like T₂, indicating that the observed efficacy was primarily attributable to carfentrazone-ethyl. Overall, carfentrazone-ethyl demonstrated high efficacy against *Pistia* while remaining safe to rice, highlighting its suitability for managing *Pistia* in rice-based systems.

Discussion

Pistia stratiotes is a free-floating aquatic weed that spreads rapidly via new daughter plants from horizontally growing stolons, as well as from copious amounts of viable seed and can regenerate and start new populations from plant fragments. Early and rapid phytotoxicity is crucial for managing *Pistia*, as delayed control facilitates rapid mat

formation, leading to oxygen depletion, obstruction of the air-water interface and interference with rice growth in wetland ecosystems. The results of the present study demonstrate that rapid-acting contact herbicides are particularly effective in suppressing with high regenerative potential.

Among the herbicides evaluated, carfentrazone-ethyl and glufosinate ammonium induced rapid and pronounced phytotoxic symptoms, characterised by extensive chlorosis, necrosis and significant biomass reduction within a short period after application. However, despite its high efficacy against *Pistia*, glufosinate ammonium caused severe phytotoxicity to rice plants in the rice + *Pistia* system, limiting its applicability in cropped wetlands. This non-selective injury is attributed to its mode of action, wherein inhibition of glutamine synthetase leads to ammonia accumulation and rapid cellular death, affecting both weeds and crops (10).

In contrast, carfentrazone-ethyl emerged as the most promising herbicide for *Pistia* management in rice ecosystems. It is a post-emergence contact herbicide belonging to the phenyl triazolinone group and has been reported to be effective against broad-leaved weeds in rice (11, 12). Its herbicidal activity involves inhibition of protoporphyrinogen oxidase (PPO) in the chlorophyll biosynthetic pathway (13), resulting in the accumulation of phototoxic porphyrins, membrane lipid peroxidation, chlorophyll destruction and rapid tissue desiccation. In the present study, this mechanism translated into rapid wilting and complete drying of *Pistia*, while rice plants remained unaffected, confirming its selectivity and crop safety.

The superior performance of carfentrazone-ethyl over auxin-mimicking herbicide 2,4-dichlorophenoxyacetic acid (2,4-D) and acetolactate synthase (ALS)-inhibiting herbicides such as bispyribac sodium and chlorimuron + metsulfuron can be attributed to its direct and rapid disruption of photosynthetic tissues. The ALS inhibitors exhibited slower symptom development and limited efficacy on the aquatic macrophyte, while the reduced effectiveness of auxin mimics may be related to restricted vascular translocation in *Pistia*. The comparable efficacy of the combination treatment (carfentrazone-ethyl + chlorimuron + metsulfuron) further indicates that control was primarily driven by the PPO-inhibitory action of carfentrazone-ethyl.

Fresh biomass reduction data corroborated visual phytotoxicity observations. Treatments involving carfentrazone-ethyl, glufosinate ammonium and acetic acid resulted in drastic reductions in *Pistia* biomass, whereas sodium chloride, lime and gypsum were ineffective and comparable to the untreated control. The absence of regrowth up to 20 DASP in effective herbicide treatments suggests complete destruction of meristematic and stoloniferous tissues, which is essential for long-term suppression of *Pistia* populations.

Table 1. Effect of herbicides and alternative chemicals on biomass of *Pistia* and weed control efficiency

Treatment	Biomass (g per pot)	Weed control efficiency (%)
T ₁ : Glufosinate ammonium at 0.50 kg ha ⁻¹	4.2	99.3
T ₂ : Carfentrazone-ethyl at 0.02 kg ha ⁻¹	7.3	98.7
T ₃ : 2,4-D (Na salt) at 0.8 kg ha ⁻¹	24.9	95.6
T ₄ : Bispyribac sodium at 0.025 kg ha ⁻¹	108.3	80.7
T ₅ : Chlorimuron ethyl + metsulfuron methyl at 0.004 kg ha ⁻¹	24.1	95.7
T ₆ : Chlorimuron ethyl + metsulfuron methyl + carfentrazone-ethyl (0.004 + 0.02 kg ha ⁻¹)	12.3	97.8
T ₇ : Sodium chloride (5 %)	524.4	6.4
T ₈ : Acetic acid (5 %)	3.8	99.3
T ₉ : Lime at 0.1 kg m ⁻²	548.8	2.1
T ₁₀ : Gypsum at 0.1 kg m ⁻² control	566.5	1.1
T ₁₁ : Control	560.3	-
CD (p = 0.05)	49.19	

Although acetic acid (5 %) caused immediate bleaching and rapid suppression of *Pistia*, its severe phytotoxic effects on rice plants preclude its use in rice ecosystems, despite its classification as an eco-friendly option. The non-selective acid-mediated tissue injury limits its practical applicability in cropped wetlands.

The efficacy and environmental safety of carfentrazone-ethyl observed in this study are supported by earlier reports. Carfentrazone-ethyl is characterised by its rapid degradation in the environment, primarily through hydrolysis to carfentrazone-chloropropionic acid, which is then further metabolised by soil and aquatic microorganisms. Photolysis also contributes to its degradation in aqueous environments (14). In another study, *Pistia* was shown to be highly susceptible to carfentrazone-ethyl, with an EC_{50} value of 26.9 g ha⁻¹ and carfentrazone-ethyl together with its primary metabolite exhibited a short half-life ($\approx$ 83 hr) in pond water, rapid dissipation from the water column and negligible sediment persistence, confirming its classification as a reduced-risk herbicide (15). Rice field applications of carfentrazone-ethyl at 119 g ai. ha⁻¹ and 224 g ai. ha⁻¹ produced pseudo-first-order half-lives ($t_{1/2}$) of 6.5 to 11.1 hr in water and 37.9 to 174 hr in sediment (16). Reports also show no residual carryover effect of carfentrazone applied in wheat crop on the succeeding sorghum crop (17).

Validation under the rice + *Pistia* system further emphasised the practical relevance of these findings. While acetic acid and glufosinate ammonium effectively controlled *Pistia*, their phytotoxicity to rice restricts their use in cropped wetlands. In contrast, carfentrazone-ethyl, alone or in combination with chlorimuron + metsulfuron, provided effective control of *Pistia* without adverse effects on rice, highlighting its suitability for integrated aquatic weed management. Overall, the study identifies carfentrazone-ethyl as a fast-acting, selective and environmentally safer option for managing *Pistia stratiotes* in flood-prone lowland rice ecosystems.

Conclusion

Application of carfentrazone-ethyl at 0.02 kg ha⁻¹ was found effective for rapid and effective control of *Pistia stratiotes* while remaining safe to rice. In contrast, glufosinate ammonium and acetic acid, despite their efficacy against the weed, were unsuitable due to their non-selective nature. Further validation through field-level trials is recommended to arrive at more conclusive recommendations.

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Authors' contributions

DT carried out the study, analysed the results and drafted the manuscript. PP contributed to project formulation and funding. NJ participated in the project formulation, study design and technical programme. SAK participated in the study design and coordination. All authors have read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

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Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT to improve the language. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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