International Journal of Environment and Climate Change

Volume 14, Issue 7, Page 577-589, 2024; Article no.IJECC.119612
ISSN: 2581-8627
(Past name: British Journal of Environment & Climate Change, Past ISSN: 2231–4784)

Germination Ecology and Ecology-based Management of *Fimbristylis miliacea* (L.) in Lowland Rice: A Review

Sethulakshmi V.S. [a*], Ameena M. [a], Arindam Deb [a], Nimmy Jose [b], Fathima Umkhulzum S. [a], Renjan B. [c], Shilpa S. [a] and Shifina Shanavas [a]

[a] Department of Agronomy, College of Agriculture, Kerala Agricultural University, Vellayani, Thiruvananthapuram, Kerala - 695 522, India.
[b] Rice Research Station, Kerala Agricultural University, Moncompu, Thekkekara P.O Kerala, Alappuzha 688503, India.
[c] Farming System Research Station, Kerala Agricultural University, Sadanandapuram, Kottarakkara, Kollam, Kerala, 691531, India.

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/ijecc/2024/v14i74295

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://www.sdiarticle5.com/review-history/119612

Review Article

Received: 07/05/2024
Accepted: 11/07/2024
Published: 15/07/2024

ABSTRACT

Fimbristylis miliacea (L.) Vahl, commonly referred to as globe fringerush, member of the Cyperaceae family, is a significant and widespread sedge weed in rice cultivation. This C_4 plant is characterized by its tall, annual or perennial growth, featuring a fibrous root system and smooth

**Corresponding author: E-mail: vssethulekshmi@gmail.com;*

Cite as: *V.S., Sethulakshmi, Ameena M., Arindam Deb, Nimmy Jose, Fathima Umkhulzum S., Renjan B., Shilpa S., and Shifina Shanavas. 2024. "Germination Ecology and Ecology-Based Management of Fimbristylis Miliacea (L.) in Lowland Rice: A Review". International Journal of Environment and Climate Change 14 (7):577-89. https://doi.org/10.9734/ijecc/2024/v14i74295.*

stems, often producing vigorous tillers reaching heights of 80-90 cm. Seedlings of *F. miliacea* typically emerge shortly after rice is planted, with flowering occurring within about a month, capable of producing a second generation within the same growing season. Found extensively throughout tropical regions, especially in lowlands, *F. miliacea* thrives in environments such as rice fields, shallow water along ditches, and streams, notably prevalent across South and Southeast Asia, as well as Australia. This weed presents enduring challenges across diverse agro-ecosystems due to its various ecotypes, prolific seed production, rapid germination, vigorous growth, strong competitive abilities and allelopathic interactions. Temperature is a critical factor significantly influencing seed germination of *F. miliacea* which exhibits non-deep physiological dormancy. Light is essential for the germination of this weed showing positive photoblastic behaviour. *F. miliacea* thrives in saturated soils but fails to emerge from depths greater than one cm, emphasizing the importance of shallow tillage to manage weed emergence effectively. Effective weed management hinges on a deep understanding of the factors that favour its emergence and establishment. Adopting the germination ecology-based practices such as tillage, stale seed bed preparation, optimal planting density, water management and nutrient management can significantly improve the management of *F. miliacea*.

Keywords: Allelopathy; chemical management; dormancy; germination ecology; sedge weed; Fimbristylis miliacea.

1. INTRODUCTION

Fimbristylis miliacea (L.) Vahl, popularly known as ‘globe fringerush’, ‘grasslike fimbry’ or ‘hoorahgrass’ belonging to the Cyperaceae family, is a serious and widespread weed of rice [1]. Out of 1800 species reported as weeds of rice, those belonging to the Cyperaceae family is found to be predominant. Cyperaceae consists of 90 genera and 5,500 species, and its range is worldwide except for Antarctica [2]. The third-largest genus in the family, *Fimbristylis* Vahl, is characterised by its great diversity, which includes an estimated 316 species [3] with Southeast Asia as its major centre of distribution. Recognized as one of the world's most problematic weeds, *F. miliacea* was reported in 95 countries. In some countries, it is also known as *F. quinquangularis* (Vahl) Kunth.

F. miliacea is a tall, annual or perennial sedge with a fibrous root system, lacking hairs, and vigorously producing tillers up to 80-90 cm in height [1]. The sedge, which is most prevalent in rice fields, is also known to invade banana, maize, sugarcane and sorghum crop field [4]. Due to its C_4 photosynthetic pathway, *F. miliacea* is likely to exhibit greater drought tolerance and competitiveness than rice crop. *F. miliacea* reproduces year-round through seeds, with a potential of producing 10,000 seeds per plant. These seeds germinate promptly upon maturation. In rice fields, *F. miliacea* seeds sprout shortly after the rice is planted and begin flowering within about a month, enabling the production of a second generation within the same growing season [1].

F. miliacea is a challenging annual sedge in rice fields across numerous countries. Regarding the yield loss in direct-seeded rice through weeds, it was found that under unweeded conditions, yield loss assessed through weed index was 75.60 percent, with a benefit-cost ratio (BCR) of 0.87 [5] and yield reductions of 43% observed in particular in rice fields dominated by *F. miliacea* [6]. In wet direct seeded rice, uncontrolled growth of another sedge weed similar to globe fringe rush called rock bulrush (*Schoenoplectus juncoides*) resulted in an 81% decrease in net income compared to the most cost-effective weed management approach [7]. However, the loss in rice yield owing to the presence of a grass weed called weedy rice observed at a density of 7.3 plants per square meter or 175 grams per square meter was 40.23% in lowland rice under wet seeding [8].

2. GLOBAL DISTRIBUTION AND HABITAT

F. miliacea, a tropical American annual sedge has become globally widespread, ranks among the top ten most prevalent weed species in rice cultivation, particularly noticed in Southeast Asia [9]. Contaminated seeds are a common introduction pathway for *F. miliacea*. Ho [10] identified *F. miliacea* as a major weed species based on density in various rice ecosystems including transplanted, wet-seeded, and dry-seeded rice in Muda, Malaysia. Chin and Mortimer [11] noted the dominance of *F. miliacea* in wet-seeded rice in the Mekong Delta of Vietnam. *Cyperus iria*, *Cyperus compressus*, and *F. miliacea* characterized by the C_4 photosynthetic pathway, were the predominant cyperaceous weeds observed throughout all growth stages of semi-dry seeded rice [12]. Sekhar et al [13] noted the prevalence of this sedge species, particularly *F. miliacea* in the wet direct seeded rice fields in the Thiruvananthapuram district of Kerala. This species is prevalent across many countries in Southern and South-eastern Asia, such as, Bangladesh, Bhutan, India, Pakistan, Indonesia, Malaysia, Myanmar, Nepal, the Philippines, Sri Lanka, Thailand, Cambodia, Australia and Vietnam. It has also been introduced to Ecuador, Madagascar, Nicaragua, Peru, and Suriname [1].

In India, Karthikeyan et al [14] documented 90 species of *Fimbristylis* (102 taxa), while Wadoodkhan [15] identified 102 species (123 taxa) within the Western Ghats, along the West Coast, and in Maharashtra. Additionally, 116 species were reported from India, with 60 species recorded from Kerala [16,17]. Recent data suggests that this number has expanded to approximately 320 species [18]. These plants are mainly distributed across tropical and subtropical regions, with some also found in warm temperate zones.

F. miliacea is widespread in tropical regions and typically found in moist, open areas. A number of tropical and subtropical regions as well as Australia are home to this species, which thrives in paddy fields, shallow water in ditches and streams [19]. In Brazil, this species flourishes, especially in rice fields cultivated under irrigation. It rapidly establishes dense populations, posing significant challenges for control and consequently increasing cost of production. It extends its reach to reservoirs, irrigation and drainage canals, and the backwaters further expanding its presence beyond rice fields. Another important weed of this family *Schoenoplectus juncoides* also proliferated abundantly in water channels, lowlands, undisturbed fields, and field bunds as an annual or perennial plant [20].

3. GLOBE FRINGE RUSH IN RICE ECOSYSTEM

F. miliacea is a prominent weed often associated with lowlands under both transplanted and directly seeded rice fields [21]. In direct-seeded rice (DSR), the uncontrolled proliferation of weeds leads to the highest nutrient removal rates, with 43.05 kg/ha of nitrogen, 3.08 kg/ha of phosphorus, and 48.28 kg/ha of potassium in weedy check plots [22]. While cattle consume *F. miliacea*, the seeds largely remain undigested and germinate near where they are deposited in dung. It poses a serious threat to rice cultivation due to its prolific seed production, which facilitates rapid colonization of new areas, resulting in significant yield losses of up to 42% when left uncontrolled. This species also causes substantial damage through plant lodging, affecting mechanized harvesting and overall crop productivity, particularly in areas with irregular irrigation practices. Additionally, the competitive nature of *F. miliacea* in root zones reduces nutrient absorption for other plants, further exacerbating crop yield reductions. Moreover, *Fimbristylis* species act as alternate hosts for a range of diseases, insects, and nematodes, compounding agricultural challenges and underscoring the urgent need for integrated management strategies to mitigate their adverse impacts on rice production. The impact of *F. miliacea* competing with rice at various growth stages was studied. The highest grain yields were achieved under weed-free conditions at 56 DAS, 70 DAS, and throughout the season. Season-long weed competition reduced grain yield by 42.35%, and concluded that maintaining weed-free conditions from 14 to 28 DAS was crucial to prevent a 5% yield loss [23].

In the Kole lands of Kerala, sedges such as *F. miliacea*, *Cyperus difformis,* and *Cyperus iria* were identified, with *F. miliacea* exhibiting a higher population compared to *Cyperus* spp [20]. *F. miliacea, C. difformis* and *C. iria* were the sedges commonly found with low land rainfed wet seeded rice in Thiruvananthapuram district [24]. The persistent application of grass killers in wet-seeded rice cultivation has led to a notable transition in weed composition towards sedges, particularly *F. miliacea*, which poses a significant threat to rice due to its prolific seed production capability enabling rapid colonization of new areas. Uncontrolled *F. miliacea* alone caused a 42% reduction in rice grain yields [25]. The main damage inflicted by this species in irrigated rice is plant lodging, significantly impacting mechanized harvesting and yield, particularly noticeable in areas with irregular irrigation [26]. Higher infestations of globe fringerush are commonly observed in non-uniformly irrigated regions, leading to potential yield losses of upto 73% [27], depending on population and crop management strategies.

F. miliacea possesses a unique ability to sustain continuous seedling emergence throughout the entire crop cycle, contributing to its significance as herbicide use becomes more widespread. This continuous emergence allows for both competitive interactions and seed production. With other species being controlled by herbicides, *F. miliacea* can compete more effectively. *F. miliacea* exhibits greater biomass production under aerobic (water-stressed) conditions compared to saturated conditions, contrasting with rice, which shows the opposite growth response [28]. Unlike rice, which utilizes a C_3 photosynthetic cycle, *F. miliacea* employs a C_4 pathway, known for its higher water productivity and potential to mitigate challenges associated with photorespiration in hot and dry environments [29]. This weed has the ability of strong competition on the roots so as to reduce the absorption of nutrients for other plants [30]. Bulrush was also found to lodge one week after reaching spike maturity, which occurred on the 40th day of its growth [20].

4. BIOLOGY

F. miliacea is a perennial plant characterized by an upright and flattened stem. Its leaves are linear, flat, and soft, arranged in two rows with overlapping edges. The plant produces numerous spikelets that are globose to ovoid in shape and typically brown to brownish-orange in colour [31]. It is an annual or perennial erect sedge with fibrous root system, without hairs, strongly tillering to a height of 80-90 cm. The culms exhibit a slender morphology, reaching heights of 40 to 60 cm, with a transverse section characterized by a four-angled, somewhat flattened shape. The leaves are linear and thread like, possessing a stiff texture, arranged in two ranks, 1.5 to 2.5 mm wide, and up to 40 cm in length, with basal leaves measuring half the length of the culm. The bract of leaf is shorter than the inflorescence. The inflorescence is a compound umbel, appearing rather lax and diffuse, measuring 6 to 10 cm in length, and exhibiting a globose or sub globose shape. Each umbel ranges from 2.5 to 4 mm long and 1.5 to 2 mm wide, typically round or acute at the apex, with a reddish-brown coloration; the lower scales detach prematurely. The stigmas are three-branched, although occasionally, in a few flowers, they may be branched into two. The anthers are yellow, and the glumes are ovate and brown, approximately 1 mm long, spirally arranged, membranous, and obtuse, with a broad green midvein or keel. The fruits are achene in nature, exhibiting colours ranging from white to yellowish, and measuring less than half the length of the glume. They are three-angled and biconvex, widest above the middle, characterized by a fine warty texture with a slight sugary coating [32].

F. miliacea seedlings appeared three days after seeds were sown. The dates estimated for the sequential development of 10 leaves, tillers, the first 10 inflorescences, and their maturity were 28 days after emergence (DAE), 35 DAE, 49 DAE, and 63 DAE, respectively. Plant height increased significantly from 3 to 8 weeks after emergence (WAE), reaching a peak of 64.05 cm at 10 WAE. This species goes through three unique growth phases: an initial slow growth stage in the first four weeks after emergence (WAE), a rapid growth stage between 4 and 9 WAE, and a peak growth stage from 9 to 17 WAE. Early post-emergence herbicide management of this plant is most effective during the first four weeks following emergence. An average of 2.3 tillers and 134 inflorescences were produced by each *F. miliacea* plant, with 84 of the inflorescences maturing during this time. Three weeks after emerging, each inflorescence, which was made up of 48 spikelets holding 511 seeds, reached maturity. Each plant produced 42,275 seeds in total, and each 1000 seed weight weighed 0.035 g. After emergence, the seeds needed 76 days to mature [23].

Dissemination of *F. miliacea* primarily occurs through seeds, which spread *via* water, wind, and human activities. Additionally, seeds are ingested by cattle and tend to germinate in proximity to droppings. Its reproductive strategy primarily involves seed propagation, with an estimated rate of 42,275 seeds per plant [23]. Notably, a significant portion of these seeds can germinate upto 50% when deposited on the soil surface, particularly under saturated conditions or delayed flooding upto 28 days after seeding (DAS) [25,33]. Seeds could germinate right after they reach maturity and in rice fields, they emerge shortly after the rice is sown, bloom within about a month, and are able to produce a second generation within the same season [1]. The root system of *F. miliacea* in rice fields expand much faster than rice and roots aggressively spread in all directions, intertwining with and eventually encircling the rice roots, resulting in significant competition for nutrients. However, the proliferation of rock bulrush (*Schoenoplectus juncoides)* in wet-seeded paddy fields was through seeds, vegetative buds, and rhizomes [34].

5. SEED ECOLOGY

The emergence and establishment of invasive weeds in agroecosystems rely heavily on seed germination, as it impacts the number of viable seeds in seedbanks. Many weed seeds possess adaptations that allow them to remain dormant until optimal conditions for germination arise, making them persistent and challenging to control. Factors like light, temperature, soil moisture, and nutrient availability play a significant role in the germination rates of weed seeds. By understanding these factors, effective strategies to disrupt weed germination, such as using mulch, adjusting planting schedules, or applying pre-emergent herbicides can be devised. Properly managing weed seed germination reduces the weed seed bank and helps prevent future weed infestations.

a) Temperature Requirement for Seed Germination

Temperature is the second most crucial ecological factor for seed germination, with both above-ground and below-ground soil temperatures playing a key role in the reproduction and establishment of weeds [35]. It was found that around 50% of *F. miliacea* seeds germinated at 35°C, while germination was significantly lower (<15%) at other temperatures, suggesting conditional dormancy or dormancy breaking at 35°C. Incubating seeds at 35°C for 24 hours followed by transfer to 25°C resulted in 50% germination, indicating that a brief warm stratification breaks dormancy [36]. Therefore, *F. miliacea* seeds exhibited non-deep physiological dormancy. Chauhan and Jhonson [33] noted that freshly harvested *F. miliacea* seeds exhibited low primary dormancy, with germination rates of 81-94%. Germination was favoured at warmer temperatures (30/20°C and 35/25°C) compared to moderate temperatures (25/15°C). Additionally, it was found that high temperatures induced germination in *Fimbristylis littoralis*, with just 1 hour of exposure sufficient for germination [37]. However, *F. miliacea* seeds stored for 5 months at 35°C lost germinability, suggesting secondary dormancy induction due to dry storage. Surprisingly, this storage slightly increased germination at 25°C. Dry tillage induced dormancy in *F. miliacea* by limiting soil moisture, preventing the seed losses that typically happen with wet tillage.

b) Light Requirement for Seed Germination

The response of seed germination to light varies widely among different plant species. Light intensity, quality, and duration significantly influenced weed growth, reproduction, and distribution. Factors such as the spectral composition and irradiance of light, along with the physiological condition of the seeds, play crucial role in these processes [35]. Certain species require light for germination, whereas others can germinate just as effectively in either light or darkness. An experiment conducted demonstrated that seeds of *F. miliacea* failed to germinate in darkness, while warm temperature and light exposure stimulated its germination. Additionally, they observed that the emergence of seedling was the highest from seeds sown on the surface of soil, with no emergence

Fig.1. A plant of *Fimbristylis miliacea*

Fig.2. Inflorescence

Fig. 3. Fibrous root system

Fig. 4. Leaf

Fig. 5. Microscopic view of spikelet

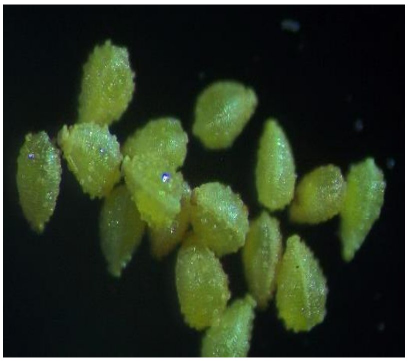

Fig.6. Microscopic view of seeds

from seeds sown at depth of 1 cm. Germination rates under light/dark regimes differed depending on temperature, with higher temperatures (30/20°C and 35/25°C) promoting greater germination compared to lower temperatures (25/15°C). Following the harvest, germination rates ranged from 81% to 94% for each species, suggesting minimal primary dormancy [33]. The studies revealed that seeds of *F. miliacea* require light essentially for germination, indicating positive photoblastic behaviour. Phytochrome, a pigment absorbing light controls this light response. Many seeds in the soil seed bank remain ungerminated due to insufficient light triggering germination. Soil disturbance can expose seeds to light, promoting germination [38]. The high germination rates immediately after harvest, indicating low primary dormancy, suggest the potential for reducing seed banks through stale seed bed techniques [39].

c) Moisture Requirement for Seed Germination

Water is significantly influential in the germination process of *F. miliacea*. Different weed species exhibit varied responses to flooding, where flooding can effectively control some weed species, while it may be difficult to manage due to their adaptability to waterlogged conditions. *F. miliacea* thrived in soil that was saturated but had no standing water [40]. Soil samples flooded until 30 days after sowing, followed by saturation and maintained under continuous field capacity conditions, exhibited higher abundance of seeds from two sedges *C. iria* and *F. miliacea* and two broadleaf species *Ludwigia hyssopifolia and Monochoria vaginalis* with *F. miliacea* being the dominant species across all soil treatments with varying water regimes [41].

d) Depth of Burial on Seed Germination

The depth of burial refers to how deeply seeds or plant parts are covered by soil during weed control operations. Optimal depth of burial is important in preventing weed emergence and promoting effective control measures. *F. miliacea* exhibited the highest emergence rate (55%) when seeds were positioned on the soil surface. However, emergence notably declined with increased burial depth, with complete absence of seedlings emerging from depths of 1 cm or greater. It was found not to emerge from even a depth of 0.5 cm [33]. In another study it was noted that, greater emergence (44%) was observed when seeds were on the soil surface, with no seedlings emerging from a depth of 1 cm [42]. *F. miliacea* seeds, being very small, rely on light for germination, which restricts their emergence to the upper soil layers [43]. Weeds characterised by small seeds typically emerge from relatively shallow depth of soil, contrasting with large-seeded weeds that can emerge from deeper layers. This indicates that adopting zero tillage methods would favour the emergence of weed species like *C. iria, C. difformis, and F. miliacea*, which are incapable of emerging from depths beyond 1 cm. Tillage operations undertaken at shallow depths to bury seeds below this depth could restrict its germination. Ameena et al [44] studied the adverse effects of the seed bank buildup from the previous year in unweeded areas where under unweeded conditions, the yield loss in direct-seeded rice, assessed through weed index was 75.60 %, accompanied by a benefit-cost ratio (BCR) of 0.87 while in the subsequent year, the yield loss peaked with a BCR of 0.70.

e) Seed Dormancy

Seed dormancy is defined as the inability of a viable seed to complete germination under favourable conditions [45]. Temperature has been identified as the primary factor influencing changes in dormancy levels [46]. It is a phenomenon that occurs at the population level, as each seed independently perceives its environment and responds physiologically to the signals it receives [47]. Both genetic and environmental factors, such as temperature, light, and soil nitrate experienced during seed maturation by the mother plant, determine seed dormancy [48]. In a study it was reported that *F. miliacea* seeds lost their capacity to germinate at 35°C after five months of dry storage [36]. This implies that the seeds underwent secondary dormancy as a result of the dry storage period. Interestingly, though, *F. miliacea* seeds at 25°C germinated more frequently after the same five months of dry storage.

In case of another similar sedge called bulrush or *S. juncoides*, fresh seeds collected after reaching physiological maturity, did not germinate under laboratory conditions where the failure could be attributed to the seed dormancy characteristic of the weed [20]. Among the cyperaceous weeds, the most troublesome C4 weed *C. rotundus* exhibited the highest rates of regrowth and viability, suggesting that the newly formed tubers readily sprouted without exhibiting any seasonal dormancy [49,50].

6. ECOLOGY BASED MANAGEMENT

Managing *F. miliacea*, requires a comprehensive understanding on factors that favour its emergence and establishment. Cultural practices significantly influence the ability of a crop to compete with weeds for both above ground and below ground resources and thereby impacting weed management practices. Many cultural practices serve as effective methods for suppressing weeds, and improving their efficiency can lead to more successful weed control. Furthermore, cultural control methods are environmentally friendly and can achieve even better results when used in combination with herbicides or other techniques. Cultural methods such as stale seed bed preparation, where weeds are allowed to germinate and then eliminated before crop sowing, can effectively reduce the weed seed bank.

a) Tillage

Tillage plays a crucial role in weed management, especially in controlling weeds like *F. miliacea*. It helps to bury weed seeds deeper in the soil, reducing their chances of germination and emergence. *F. miliacea* exhibited the highest emergence rate (55%) when seeds were positioned on the soil surface [33]. However, emergence declined notably as seeds were buried deeper, with no seedlings emerging from depths of 1 cm or greater. Tillage or minimal tillage practices could promote the emergence of viable seeds on the soil surface, allowing for effective control of seedlings through shallow cultivation or herbicide application [42]. Additionally, tillage disrupts weed root systems and can facilitate the incorporation of herbicides, improving their efficacy against *F. miliacea*. Tillage practices influence the dispersal and encapsulation of seeds throughout the soil profile. The resilience of *C. rotundus* to various pressures stems from its robust underground tuber network where each tuber generates multiple active buds during tillage, leading to continuous expansion [44].

The conventional tillage practices favoured the germination and emergence of *F. miliacea* as compared to any form of conservation tillage such as strip tillage [51,52]. The disturbance of soil in conventional tillage brings up dormant seeds from the deeper layer to surface of soil and hence allowing them to germinate whereas, in strip tillage minimum soil disturbance hampers this phenomenon. Initially, surface accumulation of weed seeds occur in strip tillage, but application of appropriate herbicide over years exhausted the seedbank of annual weeds such as *F. miliacea* in the surface layer. Apart from herbicides, surface accumulated weed seeds had to bear the brunt of predators and adverse climatic conditions [52]. Similarly, it was noted that limited emergence of *F. miliacea* under zero tillage and suggested no soil inversion as the primary cause for the observation [53].

b) Stale Seed Bed

The stale seed bed technique is a valuable cultural practice used to reduce the weed seed bank before planting any crop. This method involves land preparation with pre-sowing irrigation to encourage weed germination. Once the weeds have sprouted, they are killed through cultivation, application of non-selective herbicides, or shallow tillage. This approach is particularly effective in direct-seeded rice for managing weeds like *F. miliacea* and volunteer rice seedlings. Using herbicides to eliminate weeds without disturbing the soil can prevent new weed seeds from being brought to the surface. After the weeds have been destroyed, rice seeds should be sown with minimal soil disturbance. In case of *C. rotundus*, a reduction in tuber viability (20-23.3%) and regeneration (6-8 sprouts per square meter) was observed when employing a stale seedbed technique in conjunction with pre-plant application, followed by targeted post-emergence glyphosate application [54]. Glyphosate, whether used alone or in combination with 2,4-D, has shown promise in controlling the growth of *C. rotundus*, primarily because of its rapid translocation to the tubers [55].

c) Planting Density

Crop planting density is critical for weed management because it increases canopy cover, reduces sunlight that reaches the soil, and so inhibits weed germination and growth. Crops can more successfully compete with weeds for important resources such as water and nutrients, thus reducing weed growth. Additionally, altering planting density based on specific crop and environmental variables might improve weed control efficacy while maintaining crop output.[28] Rice planting density impacted the number of leaves and tillers, as well as the biomass of shoot and root and seed production of *F. miliacea* [53].

Increasing rice plant density to upto 32 plants per pot resulted in a 99.7% decline in the biomass of inflorescence of *F. miliacea*. This indicates that higher rice planting density can effectively control this weed. With such high density, inflorescence biomass production of *F. miliacea* was as low as 0.01 g per plant, suggesting it may not produce viable seeds. Consequently, enhancing planting density in aerobic rice can significantly reduce the soil seed bank of *F. miliacea* [53].

d) Water Management

Effective water management is pivotal for controlling weeds in rice fields. Each weed species has specific soil moisture requirements for optimal growth, and adjusting the timing, depth, and duration of flooding can contribute to weed suppression. While adequate water depth effectively controls many weeds, certain species remain unaffected by this method. Altering flooding time and depth can significantly suppress growth of *F. miliacea* during germination and emergence stages. Flooding during the germination and emergence stages proves more effective in controlling *F. miliacea* compared to late flooding. According to a study, flooding exerted a stronger impact on *F. miliacea* seedling emergence than on *C. difformis* and *C. iria*. Specifically, flooding at a depth of 4 cm for 4 out of 7 days reduced emergence by 93%, while flooding at 10 cm depth for 2 out of 7 days resulted in a 90% reduction. Seedlings failed to emerge when water consistently reached 2 cm or higher. Flooding notably affected the dry matter production of *F. miliacea* seedlings more than their emergence rate. Flooding at 2 cm depth for 4 out of 7 days led to a 94% decrease in *F. miliacea* growth compared to saturated soil conditions. With a shorter flooding period of 2 out of 7 days, deeper flooding to 10 cm depth was necessary to achieve a 99% reduction in biomass [33]. In a similar study it was observed that flooding depths ranging from 4 to 10 cm reduced the dry matter of *F. miliacea* by 64 to 76% when the soil was flooded at 7 and 14 days after sowing (DAS). By 21 DAS, flooding to depths of 2 cm and 4 cm only resulted in biomass reductions of 10 and 12%, respectively, whereas a 10 cm flooding depth caused a 54% decline [56].

Flooding significantly impacted the establishment, growth, and development of *F. miliacea*, especially when imposed during early growth stages at 7 and 14 days after sowing. Flooding depths of 5 cm and 10 cm for 14 to 21 days substantially reduced both emergence percentage and dry matter content of *F. miliacea*. Once the weed is established, flooding at 21 and 28 DAS required a 10 cm flooding depth for effective control. Therefore, careful water management is crucial for suppressing the germination and growth of *F. miliacea* in rice fields.

e) Nutrient Management

Nutrient management especially nitrogen, is essential for sustaining rice yield in the case of competition by *F. miliacea* [28]. The competition between rice and *F. miliacea* under varying nitrogen levels and weed densities were examined and observed that grain yields were higher with nitrogen fertilization compared to no nitrogen application, across all weed densities. Rice grain yield increased with higher nitrogen levels ranging from 100 to 170 kg/ha for weed densities up to 500 plants/m^2. However, the rice yields plateaued, and further increases in nitrogen had no significant influence on yield at a weed density of 1000 plants/m^2 or higher. At a lower weed density (250 plants/ m^2), applying nitrogen at 170 kg/ha resulted in yields comparable to weed-free treatments. This highlighted the importance of nitrogen management in mitigating the impact of *F. miliacea* on rice productivity [56].

Weeds affect crop nitrogen supply, nutrient uptake, resource conservation, and emission reduction [57]. A field study showed that increased nitrogen fertilization does not enhance the growth of *F. miliacea* when it competes with rice, suggesting that rice is more likely to benefit from the applied nitrogen fertilizer [28]. Optimal nitrogen management is essential for sustaining rice yield in the presence of *F. miliacea*, with significant yield benefits observed upto a certain weed density threshold. Beyond this threshold, additional nitrogen application does not contribute to further yield enhancement, highlighting the importance of integrated weed and nutrient management strategies in rice cultivation.

f) Allelopathy of *F. miliacea*

Allelopathy refers to the process where a plant releases chemicals that influence the growth of neighbouring plants, potentially providing an effective alternative for weed management [58]. Ismail and Siddique [59], identified the allelochemicals from *F. miliacea* and tested for their allelopathic effects on four weed species (*Ludwigia hysopifolia*, *Echinochloa colonum*, *C. iria* and *Paspalam digitatum*). Two compounds, hexanedioic acid dioctylester and di-n-octylphthalate, demonstrated inhibition of germination across all tested weed species. Hexanedioic acid dioctyl ester exhibited higher toxicity compared to di-n-octylphthalate, highlighting the potential of allelochemicals from *F. miliacea* for weed management in agricultural systems.

In another study, the allelopathic nature of *Fimbristylis* was studied for its effects on Malaysian rice varieties (MR211, MRQ74, MR220, MR84, MR232). Among these, MRQ74 showed increased melondialdehyde levels and significant reduction in chlorophyll content (64.5% of control) when exposed to *F. miliacea* debris, indicating its susceptibility to allelopathic suppression [60]. Similarly, it was observed that extracts from both the aboveground and underground parts of *F. miliacea* can inhibit *Emilia fosbergii* seeds from germinating at all concentrations tested (0.94, 1.87, 3.75, 7.5, 15, and 30%). However, these same extracts have no effect on *Lactuca sativa* L. seeds [61]. The aqueous extract of *F. miliacea* contains significant chemical substances like gallic acid, chlorogenic acid, rutin, luteolin, apigenin, acacetin, and alkaloids, which are possibly responsible for the observed effects on *E. fosbergii* seeds. Likewise, a study carried out in Bangladesh to assess the allelopathic effects of various weeds on aerobic rice revealed that the shortest shoot length (4.00 cm) was observed with the unboiled extract of *F. miliacea* [62]. The use of the crystallized allelochemical product derived from rice, applied at a low rate of 9.4 g per pot (equivalent to one-ton ha^{-1} biomass), decreased the seed survival of *F. miliacae* and other weeds. As the application rates or exposure time increased, there was a continued decrease in seed survival, eventually becoming lethal [63].

Another study demonstrated that the use of aqueous and methanol extracts of *Sapindus rarak* effectively suppressed the growth of *L. chinensis* and *F. milacea* weeds at concentrations of 25, 50, and 75%. The slowest weed growth was observed at a concentration of 75% soap nut extract [64]. Alam et al [65] studied the allelopathic effects of six rice varieties (WITA-3, WITA-4, WITA-12, Woo-Co, Fukuhibiki and Kalizira) and weedy rice on seed germination and growth of five weed species. *F. milliacea* showed the highest germination reduction (30.77%) with Woo-Co (T_4) treatment, longest mean germination time with WITA-1, and longest time to reach 50% germination (13.3 days). *F. miliacea* also had the most root length reduction (37.97%) with Fukuhibiki. These findings highlight susceptibility of *F. milliacea* to rice extract allelopathy.

7. RESPONSE TO CLIMATE CHANGE

Climate change can influence variations in vegetative growth, vigour, and competitiveness. Weeds can expand their geographic range through introduction and migration when their ecophysiological requirements are altered [66]. Most cultivated crops and weeds utilize the C_3 pathway for photosynthesis, whereas *F. miliacea* employs the C4 pathway. The C_4 pathway is more efficient under high temperatures due to the absence of photorespiration [67]. It was observed that *F. miliacea*, with its C_3-C_4 intermediate photosynthetic mechanism, dominates in double-cropped wetlands [21]. This adaptation suggests that *F. miliacea* may have a competitive advantage under changing climate conditions where temperatures are higher and water availability fluctuates. Additionally, the prevalence of this species signifies the impact of climate change on plant distribution in agricultural landscapes. Another study reported that weedy rice which is a C_3 weed cultivated in an environment with elevated CO_2 levels produced taller plants with increased anthocyanin pigmentation compared to those grown under open conditions with ambient CO_2 concentration [68]. The findings signified that the morphological adaptations observed in weedy morphotypes in reaction to shifting climatic conditions strongly indicated the capacity of the weed to remain as a persistent menace to rice farming [69]. Understanding the direct and indirect impacts of *F. miliacea* on crop yield demands comprehensive field studies over extended periods, considering its ability to affect mechanized harvesting and lodging of rice crops.

8. CONCLUSION

Despite its significance, there is a lack of comprehensive understanding regarding the biology and ecology of *F. miliacea* under conditions of multiple resource constraints. *F. miliacea* is a weed that rapidly colonizes new areas in saturated soil, making it difficult to control and its spread pattern need to be studied accurately. The species has a high seed production capability, leading to dense populations and increased competition with crops, complicating experimental designs focused on its impact. Understanding how the species adapts to various environmental stresses, such as water availability and soil conditions, it is crucial for predicting its distribution and impact under changing climatic conditions. Conducting controlled experiments in natural settings can be challenging due to the continuous seedling emergence of the species and competitive behaviour, requiring innovative approaches to study its behaviour and control measures effectively.

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 manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. IRRI [International Rice Research Institute]. *Fimbristylis miliacea; 2024.* Available:http://www.knowledgebank.irri.org/training/factsheets/item/fimbristylis-miliacea
   Accessed on:06 April 2024.
2. Maarten JM, Christenhusz and JW Byngi. The number of known plants species in the world and its annual increase. Phytotaxa. 2016;261(3):201–217.
3. Govaerts R, Koopman J, Simpson DA, Goetghebeur P, Wilson K, Egorova T, Bruhl JJ. World checklist of selected plant families. Facilitated by the Royal Botanic Gardens, Kew; 2018.
   Accessed On:21 March 2024
   Available: http:// apps. Kew. Org/wcsp/
4. CABI. Centre for agriculture and bioscience international.
   Accessed on: 30 April 2024.
   Available:https://www.cabi.org/ISC/abstract/20167800666
5. Ameena M. Stale seedbed techniques for management of weedy rice (*Oryza sativa f. spontanea* L.) in direct seeded rice. Annals of Agricultural Research. 2015;36(4):410-414
6. Pons TL, Utomo, IH. Competition of four selected weed species with rice. Biotropica. Bulletin (Association of Tropical. Biology) 1985;23:23–36.
7. Umkhulzum FS, Ameena M, Pillai SP. Comparative efficacy of herbicides against rock bulrush *Schoenoplectus juncoides* (Roxb.) Palla in wet-seeded rice. Indian Journal of Weed Science. 2018;50(4): 395–398.
8. Anjaly K, Ameena M, Jose N. Management of weedy rice (*Oryza sativa f. spontanea*) by enhancing rice competitiveness. Journal of Crop and Weed. 2018b;14(3):130-135.
9. Moody K. Weeds reported in rice in South and Southeast Asia. International Rice Research Institute; 1989.
10. Ho NK. Comparative ecological studies of weed flora in irrigated rice fields in the Muda area. MADA Monograph. 1991; 44:12.
11. Chin DV, Mortimer M. Weed management in direct-seeded rice in South Vietnam. Direct seeding: research strategies and opportunities. Los Banos, Philippines: International Rice Research Institute. 2002;349-356.

12. Arya SR, Ameena M. Efficacy of new generation herbicides for weed management in dry direct seeded system of rice. Journal of Tropical Agriculture. 2016;54(1):55-59.
13. Sekhar L, Ameena M, Jose N. Herbicide combinations for enhancing the weed control efficiency in wet direct-seeded rice. Journal of Crop and Weed. 2020b;16(3): 221-227.
14. Karthikeyan S, Jain SK, Nayar MP, Sanjappa M. Flora Indicae Enumeratio: Monocotyledonae. Botanical Survey of India, Calcutta. 1989;32–73.
15. Wadoodkhan MA. Cyperaceae of Western Ghats, West Coast and Maharashtra, Dattsons publication, Nagpur, India.2015; 149–254.
16. Viji AR, Pandurangan AG, Sivadas D. *Fimbristylis tuckeri* (Cyperaceae), a new sedge species from the Western Ghats, India. Kew bulletin.2016;71:1-5.
17. Sunil CN, Ratheesh Narayanan MK, Sivadasan M, Naveenkumar VV, Alfarhan AH, Abdul Jaleel V, Sameh MH. A new species of *Fimbristylis* (Cyperaceae) from India. Botany Letters. 2017;164(1):19-22.
18. POWO. Plants of the world online. Royal Botanic Gardens, Kew Science; 2020. Accessed on: 29 April 2024. Available:http://www.plantsoftheworldonline.org/.
19. Waterhouse DF. Biological control of weeds: Southeast Asian prospects. The Australian Centre for International Agricultural Research, Canberra, Australia; 1994.
20. Umkhulzum FS, Ameena M and Pillai S P. Biology of rock bulrush (*Schoenoplectus juncoides*) in the wet land rice fields of south Kerala. Journal of Tropical Agriculture. 2019;57(2):167-171.
21. Sekhar L, Ameena M and Jose N. Herbicides and herbicide combinations for management of *Leptochloa chinensis* in wet-seeded rice. Indian Journal of Weed Science. 2020a;52(3):211–216.
22. Reddy M S S K and Ameena, M. Influence of weed management practices on weed flora, crop yield and nutrient uptake in direct seeded rainfed lowland rice. Journal of Crop and Weed. 2021a;17(2):01-08.
23. Begum M, Juraimi AS, Amartalingam R, Rastan SOBS, Man AB Growth and development of *Fimbristylis miliacea* (L.) Vahl. Biotropia. 2008;15(1):1-11.
24. Reddy MSSK, Ameena M. Efficacy of pre- and post-emergence ready-mix herbicides in rainfed lowland wet-seeded rice. Indian Journal of Weed Science. 2021b;53(1): 88–91
25. Begum M. Biology and management of *Fimbristylis miliacea* (L.) Vahl. Ph.D. thesis, University Putra Malaysia, Serdang, Malaysia; 2006.
26. Schons RF. Assistência técnica e promoção comercial da linha de produtos Ihara na cultura do arroz irrigado. 60f. Trabalho de Conclusão de Curso (Graduação) – Centro de Ciências Agrárias, Universidade Federal de Santa Catarina, Florianópolis. Portuguese; 2009.
27. Noldin JA, Eberhardt DS, Rampelotti FT, Zunino J and Concenço G. Freqüência de plantas de Sagittaria montevidensis resistentes ao herbicida Only. In Congresso Brasileiro da Ciencia das Plantas Daninhas. Potuguese. 2004;4.
28. Awan TH, Ahmed S, Cruz PCS, Chauhan BS. Ecological studies for plant characteristics of *Fimbristylis miliacea* under multiple resource limitations in dry-seeded upland ecosystems. International Journal of Pest Management. 2020; 68(3): 256-266.
29. Edwards GE and Walker DA, editors. Leaf anatomy of C3–C4 species. 1983:C4.
30. Umami W, Kasim M, Rozen N. Effect inundation period to summed dominant ratio (SDR) and biomass rice weeds of method SRI (System of rice intensification) in Indonesia. International Journal of Environment Agriculture and Biotechnology. 2019;3(6):266215.
31. Moody K, Munroe CE, Lubigan RT, Paller EC, Barcial PM, Fabro LE, Janiya JD, Magsino GL. Major weeds of the Philippines 2nd Ed. Los Baños, Laguna, Philippines: University of the Philippines Los Baños; 2014.
32. Holm LG, Plucknett DL, Pancho JV and Herberger JP. The world's worst weeds. Distribution and biology. University Press of Hawaii; 1977.
33. Chauhan BS and Johnson DE. Ecological studies on *Cyperus difformis, Cyperus iria* and *Fimbristylis miliacea*: Three troublesome annual sedge weeds of rice. Annals of Applied Biology. 2009;155(1): 103-112.
34. Umkhulzum F and Ameena M. Integrated management of rock bulrush (*Schoenoplectus juncoides*) in wet seeded

rice. Journal of Crop and Weed. 2019; 15(3):139-144.

35. Ameena M, Deb A, Sethulakshmi VS, Sekhar L, Susha VS, Kalyani MSR, Umkhulzum F. Weed Ecology: Insights for Successful Management Strategies: A Review. Agricultural Reviews; 2024. DOI: 10.18805/ag. R-2661
36. Sumudunie HG, Jayasuriya KMG. Seed dormancy and germination of seven rice field weeds from Sri Lanka. Taiwania. 2019; 64(3).
37. Pons TL, HFGM Schroder. Significance of temperature fluctuation and oxygen concentration for germination of the rice field weeds *Fimbristylis littoralis* and *Scirpus juncoides.* Oecologia.1986;68(2): 315-319.
38. Milberg P, Andersson L, Noronha. Seed germination after short-duration light exposure: implications for the photo-control of weeds. Journal of Applied Ecology. 1996 :1469-1478
39. Rao AN, Johnson DE, Sivaprasad B, Ladha JK, Mortimer AM. Weed management in direct-seeded rice. Advances in Agronomy. 2007;93:153-255
40. Mabbayad BB. Tillage techniques and planting methods for lowland rice. M.S. thesis. University of Philippines, Los Banos, Laguna, Philippines; 1967.
41. Juraimi AS, Ahmad-Hamdani MS, Anuar AR, Azmi M, Anwar MP and Uddin MK. Effect of water regimes on germination of weed seeds in a Malaysian rice field. Australian Journal of Crop Science. 2012; 6(4):598-605.
42. Begum M, Juraimi AS, Amartalingam R, Bin Man A. and Bin Syed Rastans, SO. The effects of sowing depth and flooding on the emergence, survival, and growth of *Fimbristylis miliacea* (L.) Vahl. Weed Biology and Management. 2006;6(3):157-164.
43. Taylorson RB. Environmental and chemical manipulation of weed seed dormancy. Weed Science. 1987;3:135–154.
44. Ameena M, Geethakumari VL, George S. Allelopathic effects of root exudates of purple nutsedge (*Cyperus rotundus* L.) on growth of field crops. Journal of Crop and Weed. 2015;11:142-145.
45. Bewley JD. Seed germination and dormancy. The plant cell.1997;9(7):1055.
46. Benech-Arnold RL, Sánchez RA, Forcella F, Kruk BC and Ghersa CM. Environmental control of dormancy in weed seed banks in soil. Field Crops Research. 2000;67(2): 105-122.
47. Bradford KJ. Applications of hydrothermal time to quantifying and modeling seed germination and dormancy. Weed Science. 2002;50(2):248-260.
48. Née G, Xiang Y, Soppe WJ. The release of dormancy, a wake-up call for seeds to germinate. Current Opinion in Plant Biology. 2017;35:8-14.
49. Ameena M, Geethakumari VL, George S. Control of purple nutsedge through integrated management. Indian Journal of Weed Science. 2013;45(1) 51-54.
50. Ameena M, Geethakumari VL, George S. Allelopathic influence of purple nutsedge (*Cyperus rotundus* L.) root exudates on germination and growth of important field crops. International Journal of Agricultural Science. 2014;10(1):186-189
51. Hossain MM, Begum M, Hashem A, Rahman MM, Ahmed S, Hassan MM, Javed T, Shabbir R, Hadifa A, Sabagh AE, Bell RW. Strip tillage and crop residue retention decrease the size but increase the diversity of the weed seed bank under intensive rice-based crop rotations in Bangladesh. Agronomy. 2021a;11(6):1164.
52. Hossain MM, Begum M, Rahman MM. The behaviour of weed seed bank to different tillage and residue mulch treatments after three years of cropping in Bangladesh. Azarian Journal of Agriculture. 2021b;8(1): 29-37.
53. Jaiswal DK, Duary B, Kumar RR, AMP; Nath CP. Weed seedbank as influenced by tillage and herbicide in direct seeded rice-mustard cropping sequence in lateritic soil of eastern India. Weed Research; 2024.
54. Ameena M, Geethakumari VL, George S. Integrated management of purple nutsedge (*Cyperus rotundus* L.) in Okra. Indian Journal of Weed Science. 2006;38 (1 - 2) :81-85
55. Ameena M, George S. Control of purple nutsedge (*Cyperus rotundus* L.) using glyphosate and 2,4-D sodium salt. Journal of Tropical Agriculture. 2004;42(1-2):49-51.
56. Begum M, Juraimi AS, Amartalingum R, Omar SRS, Man A. Effect of *Fimbristylis miliacea* competition with MR220 rice in relation to different nitrogen levels and weed density. International Journal of Agriculture and Biology. 2009;183-187.

57. Kalyani MSR, Ameena M, Srinivas Y, Shanavas S, Susha VS, Sethulakshmi VS. Bio-efficacy of new herbicide molecules for weed management in grain legumes. Journal of Advances in Biology. 2024; 27(1):191–204. Available:https://doi.org/10.9734/jabb/2024/v27i1691.
58. Ameena M. Investigations on allelopathic influence and control of purple nutsedge (*Cyperus rotundus* L.). MSc. (Ag.) Thesis, submitted to Kerala Agricultural University, Thrissur. 1999;165.
59. Ismail BS, Siddique AB. Identification of allelochemicals -+ *Fimbristylis miliacea* and their allelopathic potential against weed species. Allelopathy Journal. 2012;30 (2).
60. Siddique MAB, BSI. Allelopathic effects of' *Fimbristylis miliacea* on the physiological activities of five Malaysian rice varieties. Australian Journal of Crop Science. 2013; 7(13):2062-2067.
61. Da Silva, ACM, Bezerra JJL, Prata APDN, De Souza RC, Paulino CDA, Do Nascimento TG, Da Silva SAS, Costa VDO and Duarte MC. Phytochemical profile and evaluation of the allelopathic effect of the aqueous extract of *Fimbristylis miliacea* (L.) Vahl (Cyperaceae). Journal of Agricultural Studies. 2020;8(3):310.
62. Yasmin M, Akonda MMR, Rahman MM, Seal HP. Assessment of allelopathic potential of different weeds on germination and early growth of aromatic rice. Journal of Biodiversity and Environmental Science. 2016;7(6):236-241.
63. Ho TL, Nguyen CT, Vu DC, Nguyen TT, Nguyen VQ, Smeda R. Rice by-products reduce seed and seedlings survival of *Echinochloa crus-galli*, *Leptochloa chinensis* and *Fimbristylis miliacea*. Agronomy. 2021;11(4):776.
64. Pujisiswanto H, Marah DL,Yusnite NS, Evizal R. Effectivity of soapnut extract (*Sapindus rarak*) as bioherbicide toward the growth of *Leptochloa chinensis* and *Fimbristylis miliacea*. Biodiversitas. 2022; 23(3):1222-1230
65. Alam MA, Hakim MA, Juraimi AS, Rafii MY, Hasan MM, Aslani F. Potential allelopathic effects of rice plant aqueous extracts on germination and seedling growth of some rice field common weeds. Italian Journal of Agronomy. 2018;13(2):134-140.
66. Umkulzhum F, Ameena M, Susha VS, Renjan B, Sreelekshmi, K, Sethulekshmi V S, Shanavas S. Weeds and their response to changing climate: a review. International Journal of Environment and Climate Change. 2024;14(4):768-779 DOI: 10.9734/IJECC/2024/v14i44157
67. Batts GR, Morison JIL, Ellis RH, Hadley P, Wheeler TR. Effects of CO_2 and temperature on growth and yield of crops of winter wheat over four seasons. European Journal of Agronomy. 1997;7(1-3):43-52.
68. Anjaly K, Ameena M, Jose N, Pooja AP, Umkhulzum F, Anjana S. Assessing the competing ability of weedy rice (*Oryza sativa f. spontanea*) with cultivated rice under elevated CO_2 conditions. Journal of Experimental Biology and Agricultural Science. 2021;9:368–S371.
69. Anjaly K, Ameena M, Jose N. Morphological characterisation of weedy rice morphotypes of Kerala. Indian Journal of Weed Science. 2018a;50(1):27-32.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of the publisher and/or the editor(s). This publisher and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.

© Copyright (2024): Author(s). The licensee is the journal publisher. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/119612