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Weed Dynamics in Acid Saline *Pokkali* Ecosystem of Kerala

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ABSTRACT

Background: *Pokkali* is a versatile rice- fish system of cultivation, producing naturally organic rice along the waterlogged coastal regions of Kerala. The weed flora of *Pokkali* rice fields is different from other rice ecosystems. Diverse weed flora appears in low saline phase, when rice is cultivated, but they dry up and decompose in high saline phase. With time, significant deviations have been reported in various climatic parameters and as a result, the weed spectrum has also undergone changes.

Methods: Two level stratified surveys and anotomical studies were conducted during *Kharif* 2017 and 2018 to study the weed flora in five major *Pokkali* growing blocks of Kerala. Two *panchayaths* (political village units) from each block and two *padasekharams* (group farming units) in each panchayath were selected for surveying. To understand the adaptive mechanism of weeds in saline soil condition, anatomical studies were performed on individual weed species.

Result: Cyperaceae family dominated in the ecosystem with more number of species. *Diplachne fusca* and *Eleocharis dulcis* were the major weeds. *Echinochloa crus-galli,* a dominant weed reported in earlier weed survey was found confined to very few locations and the frequency got reduced from 80% to 12.5%. In addition, *Sphenoclea zeylanica* was observed as an emerging weed with notable morphological adaptations. Floating ferns like *Najas graminea* and *Hydrilla verticillata* caused problems to aeration in the water in fields.

Key words: *Pokkali,* Rice-fish system, Weed flora, Weed shift.

INTRODUCTION

Pokkali is a sustainable and unique rice farming system in coastal saline soils of Kerala. Rice-fish is the traditional system followed with rice in the non-saline phase (June-October) and fish in the high saline phase (November-May). Soils of *Pokkali* are clayey, rich in organic matter and acidic with pH ranging from 3.1-4.8. Electrical conductivity of soil during summer months ranges from 12 to 24 dSm^{-1}. However, the salinity is washed off by heavy monsoon rains and the EC reduces to 6 to 8 dSm^{-1} making the soil conducive for rice cultivation. Tidal influxes up to a height of 1m and effluxes are typical characteristic of *Pokkali* ecosystem. Therefore, salinity, submergence and high inherent acidity are the major issues underlying this special system of rice cultivation. *Pokkali,* the most saline tolerant rice variety of the world, has proved its dominance as international donor of SalTol gene (KAU, 2013).

The weed flora of *Pokkali* rice fields is different from that of other rice ecosystems. Generally, due to high salinity, weeds never make a significant impact on crop yield. Weeds survive and dominate in *Pokkali* ecosystem by developing morphological and anatomical adaptive mechanisms. Weeds, including aquatic and semi aquatic weeds, occur during crop season and get decayed in the prawn culture season. Hence no weed management practices are taken up during crop production. With time, deviations in soil fertility status and variations in many other climatic factors like mean rainfall and number of rainy days have been observed. As a result, the weed spectrum has also undergone changes. However, not much information is available on the weed spectrum or contributing factors to weed shifts in *Pokkali* areas. Hence, this study was taken up to understand the shift in weed flora in the changing climatic scenario and to study the morphological and anatomical adaptations exhibited by major weeds in *Pokkali* ecosystem.

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MATERIALS AND METHODS

Location

Two level stratified surveys were conducted in five major *Pokkali* growing areas (blocks) of Kerala. Two *panchayaths* (political village units) from each block and two *padasekharams* (group farming units) in each *panchayath* were selected. Survey and anotomical studies was conducted during June to September, 2017 and 2018. Rice Research Station, Vyttila, situated in the middle during of the *Pokkali* tract of Kerala, was also included for the survey.

Cultivation practices of *Pokkali* rice

Pokkali system of rice cultivation is unique by virtue of its traditional cultural practices. Field preparation was initiated

during April by strengthening the bunds and maintaining water channels around the field. Fields got drained and sluices were set for controlling water levels. When the soil became dry, soil was heaped to form mounds which were then allowed to weather. With the onset of the monsoon during June, salt over the mounds got washed away and the top of the mounds became free of salts. On these mounds, pre-germinated seeds were sown. The seedlings were transplanted 25 days after sowing by dismantling the mounds. Since the organic matter content was high, no nutrients were added. Also, no plant protection measures were adopted. Harvesting of panicles alone was done in October leaving the stubbles behind to be used as fish feed. During survey, from each location, weed samples were collected from three different points having an area of 0.5 × 0.5 m^2 each adopting the quadrat method. In each field, species wise count of weeds was taken. Weed vegetation parameters like weed frequency (%), weed density (no. m^{-2}), relative frequency (%) and relative density (%) were worked out as suggested by Wentworth *et al*. (1984).

To understand the adaptive mechanisms of specific weeds, anatomical studies were performed on individual weed species. Free hand sections of the weed species *Diplachne fusca, Eleocharis dulcis* and *Sphenoclea zeylanica* were taken, stained and observed under microscope.

RESULTS AND DISCUSSION

Weed flora and weed growth

The weed vegetation in the *Pokkali* ecosystem during the rice growing season was divided into three major groups based on the site of occurrence. They were:

1. Weed flora in the actual rice fields.
2. Weeds seen on the bunds.
3. Weeds in water channels.

The predominant weeds observed in the *Pokkali* ecosystem of Kerala were *Diplachne fusca* and *Eleocharis dulcis*. A total of 40 weeds were identified from *Pokkali* ecosystem during low saline phase. Cyperaceae family dominated in the ecosystem with more number of species. The weed flora observed in *Pokkali* ecosystem is listed in Table 1.

When compared to the previous reports and surveys in *Pokkali* ecosystem, this study could identify more number of weeds in the ecosystem. Tomy *et al.* (1984) had reported the presence of fourteen species of weeds in the *Pokkali* fields, namely, *Echinochloa crus-galli, Eliocharis fistula, Fimbristylis miliacea, Monochoria vaginalis, Vallisneria spiralis*, *Nymphaea sp, Marsilea quadrifoliata, Asteracantha longifolia, Lymnophylla heterophylla, Sphenoclea zeylanica, Cyperus difformis, Ludwigia octovalvis, Salvinia auriculata* and *Eichhornia crassipes*.

Vidya (2003) reported that the *Pokkali* land possesses a unique weed flora having anatomical and morphological modifications for maintaining the salt balance in the plant. A total of 18 weeds species were observed which included three grasses, three sedges, nine broad leaved weeds and three ferns. Accordingly, the most dominant weed species of *Pokkali* lands were *Diplachne fusca* and *E. crus-galli*. *Fimbristylis miliacea* and *Eleocharis dulcis* were the dominant sedges in these areas. Compared to *C. difformis, C. javanicus* was abundantly found in the paddy field bunds. *Eichhomia crassipes, Monochoria vaginalis, Nymphaea nouchali* and *Pistia stratiotes* were the major broad leaved weeds found in water-logged conditions. Apart from these broad leaved weeds, *Sphenoclea zeylanica* and *Sphaeranthus africanus* were also worth mention due to the high adaptability to brackish water.

The weed flora observed in the present study is in conformity with the reports of weed survey conducted in coastal rice fields of known high salinity concentrations in Malaysia (Hakim *et al.,* 2013). They reported that abundant species included Cyperaceae, followed by Poaceae accounting for 47% of the species found.

Grasses

Among grasses, *Diplachne fusca* was the most predominant weed. *D. fusca* was observed in the fields during early June. It was present all over the fields and on bunds throughout the cultivation season. Peculiarly, *D. fusca* was the only grass weed in the *Pokkali* tracts which survived both in fields and on bunds. It was found in high density on and in between the mounds. *Echinochloa crus-galli* was observed at only one location.

Sedges

Three sedges were reported in the former study by Vidya *(*2003), however, the number in the present study has increased to eight, with *Fuirena umbellata, Schoenoplectus lateriflorus, Cyperus exaltatus*, *Cyperus javanicus* as

Table 1: Weed flora observed in Pokkali ecosystem of Kerala.

Fields	*Diplachne fusca, Echinochloa crus-galli, Eleocharis dulcis, Cyperus difformis, Sphenoclea zeylanica, Monochoria vaginalis, Sphaeranthus africanus, Pistia stratiotes, Hydrilla verticillata, Eichhornia crassipes* and *Nymphaea nouchali.*
Bunds and sides of bunds	*Digitaria ciliaris, Chloris barbata, Panicum repens, Fimbristylis miliacea, Kyllinga monocephala, Fuirena umbellata, Schoenoplectus lateriflorus, Cyperus exaltatus*, *Cyperus javanicus*, *Ludwigia parviflora, Sphaeranthus africanus, Mollugo pentaphylla, Phyllanthus niruri, Alternanthera sessilis, Alternanthera philoxeroides Scoparia dulcis, Hygrophila schulli, Cleome burmanii, Ipomoea sp., Digitaria sanguinalis, Lindernia sp. Pennisetum clandestianum, Acrostichum aureum and Exoecaria agallocha,Vernonia cinerea, Ageratum conyzoides*
Water channel	*Salvinia molesta, Nymphaea nouchali, Ceratopteris thalictroides, Hydrilla verticillata, Najas graminea. Rhizophora mangle, Hygroryza aristata*

additional sedges. During the nursery stage, the fields were heavily infested with various sedge species including *Eleocharis dulcis, Cyperus difformis, Fimbristylis miliacea, Kyllinga monocephala* etc. *Eleocharis dulcis* was present in the fields wherever the establishment of rice was poor. Though sedges dominated in the nursery, they later disappeared with the transplanting of rice seedlings. This might be due to the fact that in nursery stage, mounds provided a lower salinity range and sufficient aeration for their growth. *Eleocharis dulcis* was the dominant sedge observed in the nursery and also in the main field after transplanting. Along the bund, *Fimbristylis miliacea* was the major weed seen, which failed to survive in the field conditions at high salinity.

Broad leaved weeds

During the nursery stage, on the mounds, *Ludwigia* was the major broad leaved weed observed. After transplanting, *Ludwigia* was confined to the bunds with higher density. Then on, *Sphenoclea zeylanica* was the major broad leaved weed found in the field. As the number of rainy days and crop progressed, *Nymphaea* sp., *Eichhornia crassipes* and *Monochoria vaginalis* also were observed. *Sphaeranthus africanus* was also found in some plots. Floating weed *Pistia stratiotes* entered the field during occasional heavy rains and flash floods. Entry in large numbers suppressed the rice tillers, once the water level dropped. *Alternanthera sessilis* and *Ludwigia parviflora* remained predominant in the bunds in the cropping season.

Mangroves were found common on the bunds and fallow fields. *Exoecaria agallocha*, commonly seen on the bunds has become a menace to the farmers in some areas, though they are advantageous for the following aquaculture.

Ferns

The presence of *Salvinia molesta, Ceratopteris* and *Azolla pinnata* was reported in *Pokkali* fields (Vidya, 2003). Adding to this, pteridophytes like *Najas graminea* and *Hydrilla verticillata* also took a lead role in the *Pokkali* ecosystem. Heavy infestation of the ferns adversely affected aeration and water movement.

Distribution of weed flora

In this survey, it was observed that wherever the seedling establishment was poor, weed growth was found noticeable. Information on the distribution and importance of weeds in the *Pokkali* paddy fields of survey area are given in Table 2. With 75% frequency, *Diplachne fusca* was identified as the predominant weed in the area with a Relative importance value (RIV) of 27.25%. Among the sedges, *E. dulcis* was the major one (frequency-39%; RIV-16.8%). *S. zeylanica* was another well-adapted weed found in these areas; however, the frequency of its occurrence was less. But in abandoned fields, there was over dominance of *S. zeylanica* owing to its high adaptability to *Pokkali* conditions. *Ceratopteris thalictroides* and *Hydrilla verticillata* were the major ferns observed in these areas. *Echinochloa crus-galli* was observed in few spots. *Eichhornia* was found floating in between the crops and also in the side channels of the fields.

Vidya (2003) reported the presence of three grass weeds in *Pokkali*, with maximum intensity for *Diplachne fusca* (Frequency- 85%, density - 17.17 m^{-2}). Apart from this, *Echinochloa crus-galli* was also a major grass weed reported (Frequency- 80%). In the present study, more diverse weed flora was observed and the number of grass weeds increased to seven. The average frequency (75%) and density (9.83 $no.m^{-2}$) of *Diplachne fusca* has decreased over the years. The reduction in the intensity of *Diplachne fusca* favoured the introduction of other grass weeds. *Echinochloa crus-galli*, a dominant weed reported in earlier weed survey was now confined to a very few locations and the frequency was seen to have reduced from 80% to 12.5%. The frequency of *Eleocharis dulcis* has however reduced from 45% to 39% in the present study. The number of broad leaved weeds was observed almost similar to the earlier situation of 2003. *Alternanthera sessilis* was the major broad leaved observed in the ecosystem in the previous records. But in the present survey, the trend has been changed to

Table 2: Diversity and distribution of weeds observed in the actual rice field in *Pokkali* ecosystem of Kerala.

Weed	Frequency (%)	Density (no. m^{-2})	Relative frequency (%)	Relative density (%)	Relative importance value (%)
Diplachne fusca	75.00	9.52	28.68	25.83	27.25
Echinocloa crus-galli	12.50	3.00	4.78	8.14	6.46
Eleocharis dulcis	39.00	6.92	14.91	18.77	16.84
Cyperus difformis	6.25	2.34	2.39	6.35	4.37
Sphenoclea zeylanica	17.50	0.94	6.69	2.55	4.62
Monochoria vaginalis	12.50	1.00	4.78	2.71	3.75
Nymphaea nouchali	36.25	2.04	13.86	5.53	9.70
Eichornia crassipes	18.75	3.00	7.17	8.14	7.65
Pistia stratiotes	6.25	4.00	2.39	10.85	6.62
Hydrilla verticillata	31.25	3.10	11.95	8.41	10.18
Sphaeranthus africanus	6.25	1.00	2.39	2.71	2.55

dominance of aquatic weeds especially *Nymphaea nouchali* (Frequency- 36.25%). Occurrence of *Monochoria vaginalis* has also reduced in the present scenario.

In *Pokkali* ecosystem, distribution and variation in the intensity of precipitation patterns remained much more uncertain over the years. Climate change affected the frequency and intensity of rainfall and resulted in occurrences of extreme events such as floods and delayed rainfall consequently resulting in variations in soil salinity. Reduced salinity in the years of heavy rainfall favoured presence of more number of weeds in the ecosystem.

Adaptive mechanisms of important weeds in *Pokkali* ecosystem

Diplachne fusca

Diplachne fusca was identified as the most devastating weed in the *Pokkali* rice fields. Adaptation of the grass to saline soils indicates the halophytic nature of the plant. The weed competed well with rice gaining heavy biomass accumulation and succulence. Plants grow to a height of about 180 cm with 20-25 number of tillers producing good biomass (Plate 1a,b).

Presence of Kranz anatomy was observed in cross section of leaves of *D. fusca*, a typical feature of C4 grasses. As a result of high photosynthetic efficiency, plants grow bigger in size which is attributed to the dilution effect or succulence. This is an important tolerance mechanism in saline environments (Vidya *et al*. 2004) to dilute the toxic concentrations of ions taken up. *D. fusca* was not affected by the salinity and this species had greater shoot fresh and dry matter yields at all salinity levels (Ashraf and Yasmin, 1997). High root volume was observed for *D. fusca* in *Pokkali* ecosystem. Borzouei *et al.* (2015) observed that more root volume in salinity was due to higher salt tolerance of plants.

In saline soils, higher Na content and the resultant high ratio between Na and other cations like K, Ca and Mg within the plant become detrimental for crop. Maintaining a low ratio of Na with other cations especially with K, is considered to be an yield determining and salt tolerance criterion in crops. In the present study, analysis of K^+/Na^+ and Ca^{+2}/Na^+ in the plant showed that the ratio of K^+/Na^+ (3.58) and Ca^{+2}/Na^+ (4.47) was high at saline conditions (EC-5 dSm^{-1}).

Anatomical studies of the weed were done and the observations are illustrated in Plate 1a. Anatomical studies showed the presence of micro-hairs in *D. fusca*. Concentration of potentially toxic ions within the tissue can be maintained to lower levels by such excretory mechanisms. Thus, under adverse edaphic conditions, these mechanisms help the plants in growth and survival (Joshi *et al*., 1983). In the weed species, the presence of aerenchymatous tissues was observed very conspicuously which help them to withstand the submerged conditions.

Plate 1: (a) *Diplachne fusca* in field; (b) Diplachne fusca-microhairs (leaf).

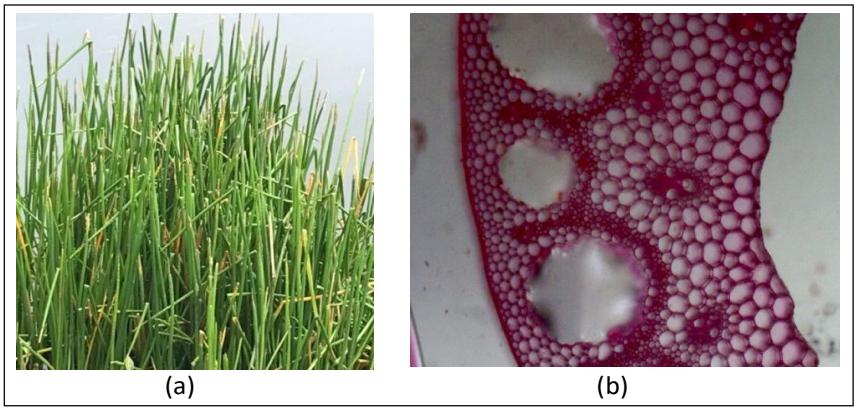

Plate 2a: *Eleocharis dulcis*. (b) *C.S. of Eleocharis dulcis.*

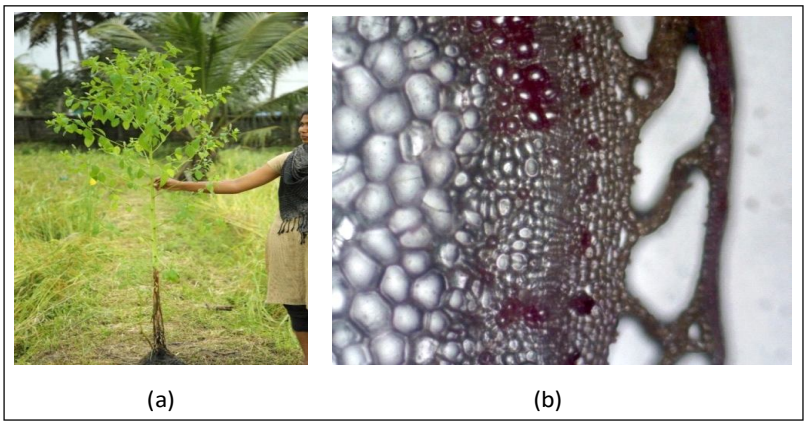

Plate 3: (a) *Sphenoclea zeylanica*. (b) C.S of *Sphenoclea zeylanica* (40 X view).

Eleocharis dulcis

Eleocharis dulcis (Burm.) Hensch. is an erect, stout and slender, perennial leafless sedge which grows throughout the year in swamps and other moist shallow areas. The plant grows from 3 to 5 feet tall, with heavy biomass and succulence. Since they are devoid of leaves, their photosynthetic requirements are met by the numerous upright tubular septate stems (Plate 2a,b).

The corms of *E. dulcis* remain in the field and survive the high saline phase and germinate the following year when low saline phase prevails in the field. The high biomass production of the weed provides better salt tolerance. In Eleocharis, the tolerance to salinity can also be substantiated by the pith formation or aerenchymatous cells developed in the plant under certain ecosystems. A higher ratio of K^+/Na^+ (14.8) and Ca^{+2}/Na^+ (4.78) observed in the present study was yet another salt tolerance mechanism in *E. dulcis* at an EC of 5 dSm^{-1} in *Pokkali* soils.

Sphenoclea zeylanica

S. zeylanica is an annual weed found invading the paddy fields, growing between the rice plants as colonies. The size of the colony increases each year, making it one of the most serious weeds in rice fields (Holm *et al*., 1977). It can cause yield losses as high as 45 per cent (Ampong-Nyarko and De Datta, 1991), when grown in high densities.

The weeds growing in salinity or submerged conditions usually tend to show higher biomass production compared to other ecosystems. This was exhibited by most of the weeds growing in the saline submerged conditions including *S. zeylanica* (Plate 3a) and many other species. The ratio of ionic distribution within the plant was also found significantly high (K^+/Na^+=4.11 and Ca^{+2}/Na^+ 8.26) at an EC of 5 dSm^{-1}.

The cross section of *Sphenoclea zeylanica* revealed the presence of aerenchymatous voids (Plate 3b). The presence of aerenchymatic tissues helps in exchange of gases between the shoot and the root systems. The well-developed aerenchyma in halophytes are generally developed on territories flooded by marine water (Hameed *et al*., 2012) and the roots with such a structure are capable of tolerating long periods of salt water flooding.

CONCLUSION

The study could identify more number of weeds in the ecosystem, when compared to the previous reports and surveys of similar areas. *Diplachne fusca* and *Eleocharis dulcis* were the major weeds. *Echinochloa crus-galli,* a dominant weed reported in earlier weed survey was found confined to very few locations and the frequency got reduced from 80% to 12.5%. In addition, *Sphenoclea zeylanica* was observed as an emerging weed with notable adaptations. Floating ferns like *Najas graminea* and *Hydrilla verticillata* caused problems to aeration in water in the fields. Weeds survive in *Pokkali* ecosystem by developing physiological adaptive mechanisms including dilution effect or high biomass production and succulence, maintaining high ratio of ionic distribution (K^+/Na^+) within the plant and anatomically by the presence of microhairs, vacuoles or arenchymatous cells.

Conflict of interest: None.

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