DIVERSITY OF *Echinochloa* spp. AND THEIR RESPONSE TO SELECT HERBICIDES

By

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(2015-11-051)

THESIS

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DECLARATION

I, Aparna K.K. (2015-11-051) hereby declare that this thesis entitled **"Diversity of *Echinochloa* spp. and their response to select herbicides"** is a bonafide record of research done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled **"Diversity of *Echinochloa* spp. and their response to select herbicides"** is a record of research work done independently by **Aparna K. K.** (2015-11-051) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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Aparna K. K.

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Introduction

1. INTRODUCTION

The most important biological constraint to rice production is weed infestation. Effective weed management plays an important role in rice cultivation to prevent yield loss, reduce production cost and ensure grain quality.

Weeds emerging under the genus *Echinochloa* are devastating and serious ones commonly associated with rice crop (Shultana *et al.*, 2013). The genus contain more than 50 species distributed throughout the world primarily in tropical and warm temperate regions (Michael, 2003). Severe infestation of *Echinochloa* spp. has been reported in wet seeded rice in 15 countries, and in dry seeded rice in 22 countries and also in transplanted rice (Rao *et al.*, 2007; Chauhan and Johnson, 2009).

Being C4 plants, *Echinochloa* have adapted to diverse environmental conditions. They have several adaptations, including the ability to flower in varying photoperiods and to produce numerous seeds which are easily dispersed. The seedlings of the *Echinochloa* closely resemble rice seedlings, and sometimes they are unintentionally transplanted to rice fields or might escape from hand weeding. They are very strong competitors with rice and can cause drastic reduction in rice yield.

Palakkad, Kuttanad, Pokkali, Kole lands and Kaippad are the main rice tracts of Kerala. Palakkad district, known as the granary of Kerala, has the largest acreage of rice cultivation in the state and contributes more than 45 per cent of the total rice produced. Though irrigated rice cultivation is mainly followed in the district due to the shortage of rain, semi-dry system of rice cultivation is also adopted by the farmers during the 'virippu' season, which coincides with the south-west monsoon. Therefore, the chances of weed infestation are high.

Echinochloa colona and *Echinochloa crus-galli* are the two major species seen in the fields of Palakkad rice tract. Recently, some new types and unidentified species of *Echinochloa* have been seen to occur in the rice fields of Palakkad district. These are believed to have been brought to the area through contaminated seeds and through mechanical harvesters which were previously used in other states, or may be due to introgression of the existing *Echinochloa* types. Farmers report that these new species or morphotypes were tolerant or less sensitive to commonly used herbicides.

Effective control of *Echinochloa* spp. relies on the selection of the appropriate herbicide, the optimum rate of application and the correct time of application, along with rotation of herbicides. Pre emergence herbicides are applied to prevent the germination and emergence of weeds whereas post emergence herbicides help to control the already emerged weeds. New generation herbicides are widely adopted by farmers as they are very effective at very low doses with low mammalian toxicity. Application of pre emergence herbicides alone or with supplemental hand weeding, or post emergence herbicides has been reported to provide a fair degree of weed control (Pellerin and Webster, 2009). Several herbicides are routinely used by farmers to control *Echinochloa* along with other weeds. Being widespread problematic weeds, development of herbicide tolerant *Echinochloa* would be a serious problem for rice farmers.

It is essential to properly identify the new species and ecotypes based on important morphological traits. Equally important is the need to test the efficacy of commonly used herbicides against these plants to pinpoint the herbicides which can be used effectively against each type. Optimization of herbicides and their doses helps in developing strategies for effective weed control. In this context, the present study was planned with the following objectives:

1) To study the diversity of *Echinochloa* spp. in the rice fields of Palakkad based on morphological characters.
2) To test the efficacy of select herbicides against *Echinochloa* spp. of Palakkad rice tract and also from the rice tracts of Kole lands and Kuttanadu in pot culture study.

Review of literature

2. REVIEW OF LITERATURE

Literature on the distribution, eco-biology, and management of *Echinochloa* is reviewed in this chapter.

1. Distribution of *Echinochloa* spp. in the world

The grass genus *Echinochloa* contains about 50 species distributed throughout the world primarily in tropical and warm- temperate regions (Michael, 2003). It include serious weeds in agriculture, with two species, viz., *Echinochloa crus-galli* (L.) and *Echinochloa colona* (L.) being the third and fourth most important weeds in the world (Holm *et al.*,1977). *Echinochloa crus-galli* (L.) is dispersed worldwide (Barret, 1983). According to Koo *et al.* (2000), *Echinochloa* is one of the most damaging weeds of rice and other crops globally. Weeds belonging to *Echinochloa* species vary in their growth habit, distribution, and morphology (Barret and Wilson, 1983). The morphological characters of *E. crus-galli* have been seen to be affected by soil type and fertility level (Martines *et al.*, 1999). *Echinochloa colona*, a native of India, is a widespread weed of rice distributed throughout the tropics and sub-tropics to warm temperate areas (Holm *et al.* 1977). *Echinochloa stagnina* is a troublesome weed distributed in the floating rice zones of Southeast Asia and tropical West Africa (Yabuno, 1968). Severe infestation of *Echinochloa crus-galli* was reported from 22 countries in dry seeded rice and 15 countries in wet seeded rice (Rao *et al.*, 2007).

2. Distribution of *Echinochloa* spp. in Kerala especially in Palakkad district

Paddy fields are a vital part of Kerala's environment and ecological systems. Palakkad and Alappuzha are the two major rice-producing districts of Kerala. Within Palakkad district, Chittur, Alathur, Kuzhalmannam, Kollengode, Nenmara and Palakkad are the blocks in which paddy production is concentrated, and productivity in rice cultivation is relatively high in this region (Thomas, 2011).

Palakkad district is the rice bowl of Kerala, where the major weed in the rice crop is *Echinochloa* spp. accounting for SDR above 11 and these species are a more serious problem in *Rabi* season than in *Kharif* (AICRP, 2009). A survey conducted by Latha and Jaikumaran (2015) revealed that, grassy weeds were the most serious problem in Kole lands of Kerala and *Fimbristylis miliaceae* and *Echinochloa colona* were the most frequent and most densely occurring weeds in Kole wetlands. Menon and Prameela (2015) reported that *Echinochloa* was the main grass weed in direct seeded rice of Kole lands in Thrissur and the main species recorded were *Echinochloa colona, Echinochloa crus-galli* and *Echinochloa stagnina. Echinochloa crus-galli* and *Echinochloa stagnina* contributed 17 percentage of the grass weed population in direct seeded rice in Kole lands (Jacob *et al.,* 2014). *Echinochloa crus-galli* and *Echinochloa stagnina* were the dominant grass weeds of transplanted rice in Alappad Kole lands of Thrissur district (Menon *et al.*, 2016). Paddy fields of Kuttanad were dominated by the grass species *Echinochloa stagnina* and *Echinochloa glabrescens* during rabi season in wet seeded rice (Raj *et al.*, 2013).

3. Eco - Biology of *Echinochloa* species

3.1. *Echinochloa crus-galli*

3.1.1. Ecology

Echinochloa crus-galli is locally known as barnyard grass. It is an annual plant ecologically similar to rice and among the *Echinochloa* species, *Echinochloa crus-galli* is the most problematic and serious competitor weed associated with rice crop (Auld and Kim, 1996). The plant can grow in diverse environments and its growth habit also varies according to the environment (Yabuno 1968). The morphological traits of barnyard grass are affected by soil type, fertility level, and cultural regimes (Holm *et al.,* 1977). It is adapted to temperate regions and anaerobic conditions such as rice fields and wetlands. It is a water loving plant, and dry soil conditions reduce the plant growth while wet conditions promote early flowering (Maun and Barret, 1986). Barnyard grass prefers wet soil with high nitrogen content and sunny places, can germinate in standing water and it tillers profusely (Auld and Kim, 1996). *Echinochloa crus-galli* grows in rice fields, water edges and marshes (Chin, 2001). The broad ecological tolerance such as the ability to mimic rice, quick germination, rapid growth and abundant seed production make it a strong weed in nearly 60 countries (Barret, 1983). The barnyard grass population exhibit wide range of phenotypic variation in many morphological characteristics. Several characteristics used to distinguish between the taxa, including spikelet hairiness and awn length are variable even within individual plants. The length of awns on the lower lemma varies considerably, often within a single inflorescence or plant (Darbyshire, 1967).

3.1.2. Germination

Germination in *E. crus-galli* is hypogeal; mesocotyl elongates, pushes coleoptile toward soil and plumule is enclosed in coleoptiles (Maun and Barret, 1986). The plants propagate only by seeds and vegetative propagation has not been observed. The ideal soil pH for germination is 7 even though the germination can take place at the soil pH range of 4-8 (Bajwa *et al.,* 2015). According to Takahashi (1978), barnyard grass germinate in the temperature range of 10 to 42°C with optimum germination at a range of 30 - 33°C. At temperatures lower than 20°C, germination was uneven and took more number of days. Shading or dark treatment lowered the percentage of germination to 30 - 40 per cent, but it was increased to 80 - 90 per cent by illumination for a quite short period such as 1 minute. Chauhan and Johnson (2011) also reported that light was not an absolute requirement but it could stimulate seed germination. However most accessions of *E. crus-galli* were of optimal germination when tests were conducted between 25 to 30°C, but both positive and negative photoblastic responses were sometimes expressed, even at lower temperatures (Kovach *et al.*, 2010). Anaerobic condition reduced seed germination. At an oxygen content lower than 10 per cent, germination was delayed and suppressed as the content decreased, but germination was observed in an environment containing only 2 per cent oxygen (Takahashi, 1978). Seeds placed on the soil surface gave maximum germination percentage (92 %), and emergence declined with increasing burial depth in soil and there were no seedlings emerged from a depth of 8 cm. Early and deep flooding significantly suppressed seed germination (Chauhan and Johnson, 2011). Rapid and good germination with high percentage of germinated seeds was observed when the soil moisture content was about 70 per cent to the maximum water holding capacity. Germination became uneven and delayed in the soil with 30 per cent moisture content, and ceased with 20 per cent moisture content. On the other hand, in the soil with the moisture content higher than 90 per cent, germination was observed only when the seeds were not covered with soil (Takahashi, 1978). Addition of high level of rice residue (6 ton ha^{-1}) to the soil surafce have a negative effect on seedling emergence and seedling biomass (Chauhan and Johnson, 2011).

3.1.3. Dormancy

Freshly collected seeds of *E. crus-galli* exhibited innate dormancy, and the duration of the dormancy varied considerably (Barrett and Wilson, 1983). The seed could remain in the field in a dormant state for a prolonged period of time (Di Nola and Taylorson, 1989). The dormancy is due to the pericarp and epidermis (Arai and Miyahara, 1963). According to Rahn *et al.* (1968), fresh seeds had only 0.3- 1.4 per cent germination. Storage of seeds for 4 and 8 months increased germination to 19 and 44 per cent respectively. The most effective methods of breaking dormancy were removal of outer seed covering or pericarp, freezing and thawing for 4 days, exposing moist seeds to 120˚F (49˚C) for 5 h, soaking them in acetone for 20 min, in concentrated H_2SO_4 for 8 min, or in water for 4 days (Rahn *et al.*, 1968). He also found no evidence of deterioration in viability of *E. crus- galli* seeds after storage for 3 years in a glass jar in lab (dry) or loam soil at two depths (8 and 25 cm). No reduction in germination of seeds buried in submerged soil for 30 months was observed by Roche and Muzik (1964); however, seeds buried at 10 cm and 20 cm depths under normal soil conditions for the same period lost considerable viability.

Dawson and Bruns (1975) buried seeds of *E. crus-galli* at 20 cm depth and found that the seeds had highest germination in the second year after burial and those buried for 13 years had 3 per cent viability, but those buried for 15 years were non-viable. Sadeghloo *et al.* (2013) reported that germination of barnyard grass would be more in acidic soil than in alkaline soil.

3.1.4. Biology

Barnyard grass is a very competitive C_4 annual grass with a chromosome number of 2n=54. It can grow up to a height of 1–2 m. The stem is stout, spongy and tufted. Culms are erect and ascending with wide phenotypic variations. Its leaves are linear and lanceolate with a length up to 40 cm and a width of 5–15 mm. Ligules and auricles are absent. The inflorescence is a green-to-purplish apical panicle of 5–40 spike-like racemes. Spikelets are elliptical and pointed, 3–4 mm long, awned or awnless with wide variations. There are various types of *Echinochloa crus-galli* which differ in overall size, size and branching of inflorescence, degree of awning, bristliness of spikelets, and in the crowding of spikelets along the branches. Because the degree of awning in some forms depends on environmental conditions, it is difficult to fit the many varietal names. It flowers all the year round and propagates by seed. Barnyard grass prefers wet soil with a high nitrogen content and sunny places. This weed grows in rice fields, water edges and marshes (Mulligan, 1961; Michael, 1981; Chin, 2001; Shultana *et al.*, 2013). Many factors including the production of large numbers of easily dispersed seeds, seed dormancy, rapid development and the ability to flower under a wide range of photoperiods make the species a successful weed (Maun and Barrett, 1986).

3.2. *Echinochloa colona*

3.2.1. Ecology

Echinochloa colona, a native of India, is a widespread weed throughout the tropics and sub-tropics to warm temperate areas (Holm *et al.* 1977). It is a summer grass (AICRP, 2009), and is the most dominant weed species in rice (Ramachandra *et al.*, 2012). It is listed as a major weed of cassava, cocoa, coconut, coffee, groundnut, maize, sorghum, soybean, tobacco and tomato (Waterhouse, 1993). It is usually adapted to sunny or partial-shade areas associated with moist or soggy loam, silt, and clayey soils and largely occurs on damp, fertile, and heavy-textured soils receiving seasonal floods (Chauhan *et al.*, 2015). *Echinochloa colona* is usually found in cultivated areas, ditches, swamps and wetlands, waterways, waste grounds, water channels, footpaths, margins of lakes and ponds, damp habitats, and barren fields (CABI, 2015).

3.2.2. Germination

Echinochloa colona, locally known as jungle rice, does not require light for seed germination but light can stimulate its germination. It possesses the ability to germinate under a wide range of alternating day/night temperatures (25/15 - 35/25 ^{0}C). Germination in the laboratory was not affected by a soil pH range of 4 to 9, but was decreased by salinity (50 mM NaCl) and moisture stress (20.2 MPa osmotic potential). Germination of jungle rice was greatest (97 per cent) for seeds at the soil surface, but emergence declined exponentially with increasing seed burial depth, and there was no seedling emergence beyond a soil depth of 6 cm (Chauhan and Johnson, 2009). Wu *et al.* (2004), reported that the seed of this species were capable of emerging from up to the depth of 10 cm with maximum seedling emergence from 1 to 2 cm burial depth under dry land condition. Addition of crop residue at a rate of 4-6 tons ha^{-1} on the soil surface reduced the seedling emergence. As germination of jungle rice was strongly stimulated by light and seedling emergence was optimal at shallow burial depths, this species is likely to be problematic in reduced tillage systems and is favoured by a humid environment (Chauhan and Johnson, 2009).

3.2.3. Dormancy

Seed dormancy varies with different types of *Echinochloa colona*. Holm *et al.* (1977) reported some strains of *Echinochloa colona* exhibiting short period dormancy following harvest, but this dormancy disappeared in less than eight months. Ramakrishnan (1960) also reported a primary dormancy period of about two months in the freshly harvested seeds of *Echinochloa colona.* However according to Kim and Moody (1989), there is no innate or induced dormancy and seeds germinated rapidly on the surface of saturated soils but not under water. A tetrazolium test showed that 80 per cent of the initial seeds were viable and seed dormancy was lost rapidly within the first four months of burial, resulting in the emergence of seedlings (Wu *et al.,* 2004).

3.2.4. Biology

Echinochloa colona is a C4 plant with 2n = 54 (Yabuno, 1962). It is a prostrate to erect, shallow-rooted annual or occasionally perennial plant which can grow up to a height of one metre (Hru sevar *et al.,* 2015). Its seedlings are often flat and spreading with pointed tip rolled leaves with no hair (Zimdahl *et al.,* 1989). Stem of *Echinochloa colona* is green or reddish-purple. The culm is stout, erect, ascending or decumbent and often branches arise from the base and root at the lower nodes (Wagner *et al.,* 1999; Hru sevar *et al.,* 2015). Sheath is 3–7 cm long, compressed, keeled and glabrous. Leaf blade is light green in colour, sometimes with transverse purple bands, flat, glabrous, elongate, with a length of 4–10 cm and a width of 3–8 mm. Leaves occasionally have scabrous margins with acute apex. Ligule is absent. Panicle is erect or nodding, green in colour or purple-tinged. The panicle is 5–15 cm long with numerous racemes of 2-4 cm length. The racemes are spreading, ascending, sometimes branched and the upper ones are more crowded than lower ones which are up to 1 cm apart. Spikelets are green tinged with purple, crowded, and arranged in circa 4 rows. The spikelets are about 3 mm long, rarely with a short point up to 1 mm long. Caryopsis is whitish, broadly ovate, 1.7–2 mm long, flat on one side, convex on the other (Wagner *et al.,* 1999). In *E. crus-galli* the top of the body of the lemma is broadly rounded with an irregular row of hairs. The short acute tip is abruptly different in colour and texture from the body of the lemma (Darbyshire, 1967). It propagates mostly by seeds but also vegetatively, by rooting at its nodes.

3.3. *Echinochloa stagnina*

3.3.1. Ecology

Echinochloa stagnina grows in swamps, seasonally flooded grass land, pools and ditches and the weed is mainly distributed in tropical Asia and Africa (Yabuno, 1968). It is an important weed of floating rice (Michael, 1981).

3.3.2. Biology

Echinochloa stagnina species comprises a lot of diversities. According to Yabuno (1968), the species has been taxonomically confused with *Echinochloa stagnina* and according to Degener and Degener (1960) and Reed (1977), *Echinochloa picta* has been illustrated under the name *Echinochloa stagnina.* It is a stoloniferous perennial and can also reproduce by seeds. The plants often propagate vegetatively and some sterile plants of *Echinochloa picta* were also observed in Philippines and Thailand. The plant can grow up to a height of 1.8 to 2 m from long creeping and copiously rooting rhizome. Culms are geniculately ascending, rooting and frequently branching from the submerged nodes and may be slender, or more usually stout, with a diameter of about 8 mm. Ligules are transformed to fringe of hairs. The interior of the stems of the perennial strains is spongy; this character makes them suitable for underwater life, giving them reduced specific gravity and satisfactory aeration. In these strains, internodes elongate at the time of water increase; they have a floating habit. Non floating annual types of *Echinochloa stagnina* were also reported (Yabuno, 1966). The inflorescence is 10-25 cm long and spikelets are arranged in three or four rows along the branches of inflorescence. Spikelets are 4-6 mm long, usually awned with an awn length of 5-7.5 mm. Lower floret is staminate or sometimes barren (Yabuno, 1968).

4. Effect of *Echinochloa* species on rice

Weed infestation and interference are a serious problem in rice cultivation that lead to a significant yield reduction. *Echinochloa* species are the most devastating and serious weed commonly associated with rice crop (Shultana *et al.*, 2013). Yield losses due to weed competition are greater in direct seeded rice systems than in transplanted rice (Chauhan *et al.*, 2015). All *Echinochloa* species have a C_4 photosynthetic pathway and show a great advantage when grown with C_3 crops such as rice (*Oryza sativa* L.) and some of them can grow both in dry and flooded soil (Opena *et al.*, 2014). Some of the advantages such as prolific seed production, short seed dormancy, quick emergence pattern, and rapid vegetative and reproductive growth under wide-ranging photoperiod conditions ensure successful population survival under diverse environments and contribute more persistence towards its weedy nature (Wu *et al.*, 2004; Chauhan and Johnson, 2010). This weed is an example of ''crop mimicry'' as it closely resembles the rice crop at the seedling stage and is sometimes unintentionally transplanted into fields together with rice (Chauhan and Johnson, 2009). Rao *et al.* (2007) reported that *Echinochloa* competition and subsequent yield reduction were higher in direct-seeded rice than transplanted rice because of its resemblance with rice at early stages. The development of herbicide resistance in several populations of *Echinochloa* add to its importance in rice field (Vidotto, 2007).

Yield losses caused by *Echinochloa* spp. infestations in rice can be very severe and variable in relation to the cultivar and the duration of competition (Vidotto, 2007). Within the genus, *Echinochloa crus-galli* was a severe competitor for rice even at the early growth stage because all the growth parameters of the rice crop were significantly suppressed by the increasing trend of rice-weed competition durations (Shultana *et al.*, 2013). According to Holm *et al.* (1977), *Echinochloa crus-galli* may remove 60-80 per cent of nitrogen from the soil especially in the first half of the growing season and there was a drastic reduction in the number of tillers (up to 50 per cent), number of panicles, height of rice plants, weight of the grains and number of grains per plant. Swain (1967) reported that one to five plants of *Echinochloa crus-galli* per square foot could lead to a reduction in the rice yield up to 18-35 per cent and according to Chin (2001), the competition of 25 barnyard grass plants m^{-2} caused about 50 per cent yield loss.

Echinochloa colona is also a serious competitor of rice. An infestation of 40 viable seeds m^{-2} of *Echinochloa colona* resulted in yield losses ranging from 27- 62 per cent (Fischer *et al.*, 1997). According to Suriapermana (1977), season-long competition of *Echinochloa colona* caused a 43 per cent yield reduction in transplanted rice.

5. Management of *Echinochloa* spp. in rice

There are several weed management strategies including cultural, mechanical, biological, chemical, and integrated approaches adopted for the better control of a particular weed species in rice-ecosystem (Hailmi *et al.*, 2011). Cultural control method include preventive strategies. For direct seeding, sowing of rice seeds free from *Echinochloa* seeds can help to keep a check on the weed. Clean cultivation is another important aspect, which can help to control *Echinochloa crus-galli* in rice fields (Zhang, 2003). In the case of transplanted rice, inundation of the field with a layer of water immediately after transplantation could suppress the population of *Echinochloa crus-galli* (Chin, 2001). The use of competitive cultivars is another important cultural strategy employed to control *Echinochloa crus-galli*. Fast emergence, early crop establishment, quick vegetative growth, and rapid leaf area development are the plant traits which make rice plants more competitive against weeds (Mahajan and Chauhan, 2013).

Narrow row spacing, increased flooding depth, and early weed emergence proved to be effective in limiting the emergence and establishment of *Echinochloa* species and could be a noteworthy constituent of integrated weed management strategies in different cropping systems (Mahajan and Chauhan, 2013). Hand hoeing was a valuable method for controlling *E. crus-galli* particularly on small size farms of Asia (Chin, 2001) but weeds like *Echinochloa colona* and *Echinochloa crus-galli* escaped from hand weeding as they were similar to rice at the early stage and produced weed seeds that could infest crops in subsequent seasons (Chauhan, 2012). Labour shortage and high wages also made hand weeding uneconomical (Beltran *et al.*, 2012).

Various studies were conducted on the biological control of *Echinochloa* species in rice. Chung *et al.* (1990) declared *Exserohilum* species as a potential biocontrol pathogen against *Echinochloa crus-galli* as it was responsible for leaf blight of the weed. According to Motlagh (2010), two fungal pathogens, *Alternaria alternata* and *Fusarium equisetii* caused leaf blight in *Echinochloa colona* and other *Echinochloa* species. Tosiah *et al.* (2011) reported that *Exserohilum monoceras* at a rate of 10^7 spores ml^{-1} caused infection in four *Echinochloa* species. The fungus *Curvularia lunata* (B6 strain) was highly effective in suppressing *Echinochloa crus-galli* at 1–2.5 leaf stages in China (Jing *et al.*, 2013). Geng *et al.* (2009) formulated a mycoherbicide from *Helminthosporium gramineum* Rabehn f.sp. *echinochloae* in China to control *Echinochloa crus-galli*. The application of this formulation under greenhouse and field conditions helped to decrease the growth and biomass of *Echinochloa crus-galli* as well as increase the rice yield over the control without any negative effect on rice crop. Even though fungal pathogens have a potential use as biocontrol agents against *Echinochloa*, they are not considered as reliable agents for the control of weed species in crops because of their slow activity. Therefore only the use of biocontrol agents in integration with other management options can provide effective control of *Echinochloa* and other weeds (Peerzada *et al.*, 2016). Allelopathy can also play an important role in the management of *Echinochloa* species in rice. The post application of fusilade (48 g) in combination with rice straw extract at a rate of 3.5–6.9 g L^{-1} were found most effective in suppressing the growth of *Echinochloa colona* (Peerzada *et al,* 2016).

The control of *Echinochloa* species by herbicide applications has become more economical in the wake of labour shortage and high wages of labour for performing hand weeding (Beltran *et al.*, 2012). *Echinochloa* was controlled by the application of pre emergence herbicides alongside with shallow flooding. Post emergent herbicides are also an effective method in controlling weeds, especially in direct seeded rice (Chauhan *et al.*, 2012). For herbicide to be effective, the dose and time of application were most important (Haefel *et al.,* 2000). It was reported that the seedling survival percentage was increased to 100 in *Echinochloa* plants when bispyribac sodium and the combination of penoxsulam and cyhalofop were applied late at eight leaf stage instead of the four leaf stage (Chauhan and Abugho, 2011).

5.1. Pre emergence herbicides

Pre emergence herbicides or soil applied herbicides kill the weeds at the early growth stages. The efficiency of pre emergence herbicides in controlling weeds was, however, dependent on several factors such as soil moisture, soil tilth, composition of the weed flora, herbicide doses, and environmental conditions (Baltazar and De Datta, 1992). Soil-applied herbicide might either be adsorbed or absorbed or both by the seeds present in the soil; this might occur prior to or during seed germination. Adsorbed herbicides remained on the outer surface of the seed coat and might be absorbed later by the seedling as it emerged through the seed coat following germination. Absorbed herbicides, meanwhile, entered the seed by mass flow (dispersed in imbibed water) or diffusion. Seeds continued to absorb herbicides even after maximum water imbibition, hence, herbicides accumulated within the seeds at a greater concentration than in the surrounding soil solution (Anserson, 1983). So, soil moisture had a crucial role in determining the efficacy of pre emergence herbicides. Soil should be adequately saturated before application of herbicides, as it facilitated the movement of the herbicide into the soil, thereby reducing herbicide losses from the soil surface and increasing the absorption of the herbicide by the emerging seedlings (Stickler *et al.*, 1969). But the moisture should not be excess as it may detrimental to the crops. A study conducted by Peerzada *et al.* (2016) suggested that the application of herbicides should be avoided when the soil was too wet, and irrigation should be delayed at least one week after herbicide application. Pretilachlor with safener, pendimethalin, bensulfuron methyl + pretilachlor, pyrazosulfuron, oxadiargyl and oxyfluorfen were some of the pre emergence herbicides which were commonly available in India (Rao, 2013; Chauhan *et al.*, 2012; Mahajan and Chauhan, 2013; Peerzada *et al.*, 2016).

5.1.1. Pretilachlor

A study conducted by Peerzada *et al.* (2016) revealed that pretilachlor with safener was very effective against all the weed species in rice crop. In areas which had more chances for rain after herbicide application (wet season), farmers were to apply only pretilachlor with safener, as it had low phytotoxic effect. Pretilachlor at a dose of 0.075 kg ha^{-1} followed by flooding at a shallow depth of 2 cm reduced the emergence and growth of *Echinochloa colona* and *Echinochloa glabrescens,* whereas a higher dose of pretilachlor (0.3 kg ha^{-1}) alone could also reduce the weed emergence (Pablico and Moody, 1993; Dorji *et al.*, 2013; Opena *et al.*, 2014). Pre emergence application of pretilachlor with safener at 0.6 kg ha^{-1} controlled *E. crus-galli* and *E. colona* with 100 per cent weed control efficiency (Awan *et al.*, 2015).

5.1.2. Oxyfluorfen

An application of oxyfluorfen 23.5% EC at 150 g ha^{-1} followed by hand weeding at 30 days after sowing resulted in a higher weed control efficiency of 90 per cent or more in wet seeded rice (Abraham and Menon, 2015).

5.1.3. Pyrazosulfuron-ethyl

Pyrazosulfuron-ethyl at a dose of 20 g ha^{-1} resulted in significantly lower dry weight of grasses, sedges, broadleaf and total weeds in rice and hence indicated higher values of almost all yield attributes and grain yield of rice (Saini, 2003). Gowda *et al.* (2009) recommended the application of pyazosulfuron-ethyl at 30 g ha^{-1} for weed management in aerobic rice as it gave a higher grain yield. Another study conducted by Kiran and Subramanyam (2010) showed that 0.035 kg ha^{-1} was very effective in reducing the density and dry weight of weeds in rice. The density of *E. colona* itself was reduced by pyrazosulfuron ethyl at a dose of 0.015 kg ha^{-1} when applied at 3 days after sowing (Mahajan and Chauhan, 2013). Kumar and Ladha (2011) also suggested that pyrazosulfuron ethyl is an effective herbicide for controlling *Echinochloa crus-galli.* Arya and Ameena (2016) reported that the pre emergence application of pyrazosulfuron-ethyl at 25 g ha^{-1} on the day after sowing followed by azimsulfuron at 30 g ha^{-1} as post emergence application at 25 days after sowing was the best weed management practice for semi-dry rice in terms of weed control, yield attributes, yield and economics.

5.1.4. Pendimethalin

Pendimethalin is an effective herbicide for controlling *Echinochloa crus-galli* (Kumar and Ladha, 2011). Pre emergence or pre-plant incorporation of pendimethalin provided effective control of *Echinochloa colona* up to 60 days after sowing (Punia *et al.*, 2005). In direct-seeded rice, the pre emergence application of pendimethalin followed by the post emergence application of bispyribac-sodium or penoxsulam resulted in 80 per cent reduction in density of different weeds, including *Echinochloa colona* (Khaliq *et al.*, 2011). Raj *et al.* (2016) also reported the high efficacy of pendimethalin followed by bispyribac sodium against *Echinochloa colona* whereas in the same study, pendimethalin 1 kg ha^{-1} reduced the density of *Echinochloa colona* in rice field at 30 and 90 days after transplanting. According to Mahajan and Chauhan (2013), pendimethalin at 0.75 kg ha^{-1} treated at 3 days after sowing resulted in 90 per cent reduction of the density of *E. colona*. Pre emergence application of pendimethalin at 1 kg ha^{-1} suppressed the weed growth, including that of *Echinochloa colona* upto 20 days after sowing in direct-seeded rice (Nayak *et al.,* 2014). Pendimethalin followed by hand weeding achieved high grass weed control in rice throughout the season (Peerzada *et al.*, 2016).

5.1.5. Pretilachlor + Bensulfuron methyl

According to Sanjay *et al.* (2013), benzsulfuron methyl + pretilachlor at 0.06 + 0.60 kg ha^{-1} was effective for controlling weeds in aerobic rice. In direct wet seeded rice, application of bensulfuron methyl + pretilachlor (Londax power) 8-10 days after sowing at 10 kg ha^{-1} helped to control a broad spectrum of weeds (Rao, 2013). Arya and Ameena (2016) suggested that the best weed management practice for semi dry rice in terms of weed control, yield attributes, yield and economics was the pre emergence application of benzsulfuron methyl + pretilachlor at 60 + 600 g ha^{-1} on the day after sowing followed by azimsulfuron at 30 g ha^{-1} as post emergence application at 25 DAS.

5.1.6. Oxadiargyl

Kumar and Ladha (2011) reported that *Echinochloa* can be effectively controlled by oxadiargyl. Oxadiargyl at a dose of 0.075 kg ha^{-1} and more reduced the population of *E. crus-galli,* and greater efficacy against the weed was observed under anaerobic condition than aerobic condition (Gitsopoulos and Williams, 2003). Oxadiargyl has also been reported as an effective pre emergence herbicide option for reducing the density of *Echinochloa colona* by 50-70 per cent (Bridgemohan, 2014). Pre emergence application of oxadiargyl at 75 g ha^{-1} followed by bispyribac-sodium at 30 g ha^{-1} applied at 20 days after transplanting was at par with hand weeding twice at 20 and 40 days after transplanting in achieving higher grain yield (Kiran and Subramanyam, 2010). Oxadiargyl at a dose of 0.1 kg ha^{-1} reduced the dry matter production of *Echinochloa* whereas the same dose also resulted in a significant reduction of the density of *E. colona* (Bhattacharya *et al.*, 2005; Raj *et al.*, 2016).

5.2. Post emergence herbicides

Post emergence herbicides are applied after weed emergence. Cyhalofop butyl, bispyribac sodium, penoxsulam, fenoxaprop-p-ethyl, ethoxysulfuron and metamifop are some of the commonly available post emergence herbicides for weed control in rice in India.

5.2.1. Cyhalofop butyl

Cyhalofop butyl is an efficient herbicide for the selective control of grass weeds in rice especially *Echinochloa* spp. (Kumar and Ladha, 2011; Saini *et al.*, 2013). A study from Greece reported that, early post- emergence application of cyhalofop butyl at a rate of 0.15- 0.2 kg ha^{-1} effectively controlled *Echinochloa crus-galli* and the efficacy was higher in two leaf stage than that of four leaf stage (Ntanos *et al.*, 2009). A study conducted in the rice fields at Kole lands of Kerala by Jacob *et al.* (2014) suggested that, cyhalofop butyl at 80 g ha^{-1} was very effective against grass weeds when applied at 20 days after sowing. According to Menon and Prameela (2015), the post emergence application of cyhalofop butyl 100 g ha^{-1} reduced the *Echinochloa* population in wet seeded rice of Kole lands, Kerala. Abraham and Menon (2015) reported that the combined application of penoxsulam + cyhalofop butyl at 150 g ha^{-1} could result in a weed control efficiency of 90 per cent or more at 30 and 60 days after sowing.

5.2.2. Bispyribac sodium

Kumar and Latha (2015) suggested bispyribac sodium as an effective herbicide for the control of *Echinochloa crus-galli*. Jabran *et al.* (2012) also reported that *Echinochloa crus-galli* could be controlled by the application of bispyribac sodium at 25 g ha^{-1}. *Echinochloa colona* was very effectively controlled with post emergence application of bispyribac sodium at a rate of 25-30 g ha^{-1} (Walia *et al.,* 2008). Post emergence application of the herbicide at four- leaf stage reduced the biomass of *Echinochloa colona* up to 95 per cent (Chauhan and Abugho, 2012). Menon and Prameela (2012) reported that the post emergence application of bispyribac sodium at 30 g ha^{-1} was as effective as hand weeding twice. A field experiment conducted in the rice field at Moncombu, Kerala showed that the maximum reduction in weed dry weight was observed with the application of bispyribac sodium + metamifop 14 % SE at 70 g ha^{-1} (with wetter) with a weed control efficiency of 94.9 per cent which was on par with weed free situation, bispyribac sodium 10 % SC at 20 g ha^{-1} and bispyribac sodium + metamifop 14% SE at 140 g ha^{-1} with wetter during *kharif* season. However during rabi season, bispyribac sodium + metamifop 14% SE at 140 g ha^{-1} with wetter registered a better weed control efficiency of 98.9 per cent, which was on par with bispyribac sodium 10% SC at 20 g ha^{-1} and bispyribac sodium + metamifop 14% SE at 70 g a.i. ha^{-1}

with wetter (Raj *et al.*, 2013). According to the field trial conducted by GuoLan *et al.* (2014), bispyribac-sodium 10% SC (30 g ha^{-1}) had efficiency greater than 90 per cent in controlling *E. crus-galli*. Opena *et al.* (2016) reported that the application of bispyribac sodium (20 g ha^{-1}) following pendimethalin at 40 days after sowing helped in reducing weed population until crop harvest. Bispyribac sodium was found effective in rice nursery as well as main field where *Echinochloa crus-galli* and *Echinochloa glabrescens* were major problems (Duary and Mukherjee 2013). Jacob *et al.* (2014) reported that bispyribac sodium at 30 g ha^{-1} applied 20 days after sowing was the best herbicide for rice where *Leptochloa chinensis* was not a problem.

5.2.3. Penoxsulam

A weed control study in rice revealed that application of penoxsulam provided 99 per cent control of *Echinochloa crus-galli* at 21 DAT (Ottis *et al.*, 2003). Kumar and Ladha (2011) also suggested penoxsulam for the control of *Echinochloa*. Herbicides, including penoxsulam plus cyhalofop butyl and, fenoxaprop plus ethoxysulfuron provided more than 90 per cent suppression of *Echinochlioa crus-galli* (Chauhan and Abugho, 2012). A field trial conducted by GuoLan *et al.* (2014) in China revealed that penoxsulam 2.5% OD applied at applied at 22.5 g ha^{-1} produced control efficacies of more than 95 per cent at 20 and 40 days after application. According to Panozzo *et al.* (2014), penoxsulam combined with irrigation beginning 15 days after herbicide application provided efficient control of barnyard grass. A combination of penoxsulam + cyhalofop-butyl at 150 g ha^{-1} performed better than other herbicides resulting in superior control of all types of weeds, and higher grain and straw yields of wet seeded rice (Abraham and Menon, 2015) .

5.2.4. Fenoxaprop-p- ethyl

Fenoxaprop-p-ethyl at 0.06 kg ha^{-1} was efficient in selective control of annual grassy weeds in rice when applied at 26-30 days after sowing (Karim *et al.*, 2004). A significant reduction in the population of *E. crus-galli* was obtained by fenoxaprop-p-ethyl at a rate of 0.09 kg ha^{-1} (Saini and Angiras, 2002). Fenoxaprop-p-ethyl plus ethoxysulfuron gave 83 per cent control of *Echinochloa colona* when sprayed 21 days after rice sowing (Singh *et al.*, 2006). Menon and Prameela (2015) reported that, the post emergence application of fenoxaprop-p-ethyl 60 g ha^{-1} reduced the *Echinochloa* population in wet seeded rice of Kole lands, Kerala. A study conducted by Jacob *et al.*, 2014 in Kole lands of Kerala suggested that, fenoxaprop-p-ethyl at 60 g ha^{-1} was one of the best herbicides for the control of grass weeds when applied at 20 DAS. According to Peerzada *et al.* (2016), the combination of penoxsulam plus cyhalofop butyl could achieve broad-spectrum control of sedge, grasses and broadleaved weeds.

5.2.5. Ethoxysulfuron

Singh *et al.* (2006) reported that application of ethoxysulfuron at 18 g ha^{-1} at 21 days after sowing was effective for weed control of furrow irrigated raised bed system of rice cultivation. Ethoxysufuron at a rate of 0.015 kg ha^{-1} and 0.02 kg ha^{-1} showed a good result in controlling weeds as well as reducing weed dry weight (Pal *et al.*, 2008). According to Singh *et al.* (2015), application of ethoxysulfuron followed by bispyribac sodium was highly effective in controlling *Echinochloa crus-galli*. The control of *Echinochloa crus-galli* was improved by 43-69 per cent by the tank mixture of fenoxaprop-p-ethyl with ethoxysulfuron (90 + 18 g ha^{-1}) in dry seeded rice. It also reduced grass dry matter and maintained the grain yield similar to the weed free check (Bhullar *et al.*, 2016).

5.2.6. Metamifop

Metamifop at 0.09 - 0.2 kg ha^{-1} showed high weed control efficiency to annual grasses, especially *E. crus-galli* (Kim *et al.*, 2003). Menon and Prameela (2012) reported that the post emergence application of metamifop 125 g ha^{-1} reduced the *Echinochloa* population in wet seeded rice of Kole lands, Kerala. A field trial conducted by GuoLan *et al.* (2014) revealed that metamifop 10% EC at a dose of 120 g ha^{-1} produced weed control efficacies of more than 95 per cent at 20 and 40 days after application.

Successful chemical weed management programmes are usually associated with the weed population, herbicide application time, and herbicide dose (Swanton and Weise, 1991). Pre-emergence herbicide application followed by either hand weeding at 40 DAS or application of post emergence herbicides or a mixture of post emergence herbicides recorded higher weed control efficiency (Mahajan and Timsina, 2011; Chauhan and Opena, 2012). The efficacy of herbicides, however, was dependent on the growth stage of the weed. The efficacy of bispyribac-sodium, penoxsulam + cyhalofop-butyl, and fenoxaprop-p-ethyl + ethoxysulfuron on *Echinochloa crus-galli* and *Echinochloa colona*, for example, was reduced when the herbicides were applied at 8 leaf stage compared to when these were applied at 4 leaf stage (Chauhan and Abhugo, 2012). Application of post emergence herbicides at 4 leaf stage on *Echinochloa glabrescens* reduced the seedling survival but, further delay in the herbicide application to six and eight leaf stage no longer reduced the seedling survival (Opena *et al.,* 2012).

6. Herbicide resistance of *Echinochloa* species

Continuous chemical control of *Echinochloa* species in rice crop has caused herbicide resistance to many accessions (Holm *et al.,* 1977; Martines *et al.* 1999; Rutledge *et al.* 2000; Chauhan *et al.,* 2015). According to Perez *et al.* (2009), bispyribac-sodium, cyhalofop-butyl and fenoxaprop-p-ethyl were ineffective in controlling *Echinochloa colona*.Werth *et al.* (2012) reported glyphosate resistance in *Echinochloa colona* in Australia. The occurrence of penoxsulam-resistant *Echinochloa crus-galli* was a serious challenge to weed management in rice fields of China and most of the penoxsulam-resistant populations showed at least a moderate level of resistance to bispyribac-sodium, metamifop, cyhalofop-butyl and oxadiazon, whereas some populations showed at least a moderate level of resistance to oxyfluorfen and pretilachlor, pyrazosulfuron-ethyl, pyribenzoxim and fenoxaprop-p-ethyl, but the resistance indices of the populations to pendimethalin were all low (Chen *et al.*, 2016). Heap (2013) reported the herbicide resistance of *Echinochloa crus-galli* in 19 countries. *Echinochloa crus-galli* collected from direct seeded rice showed resistance against butachlor and propanil (Juliano, 2010).

Diggle *et al.* (2003) suggested that the use of more than one herbicide, either in a mixture or in a sequence, as well as the integration of other weed control methods with herbicides could help not only to control herbicide-resistant weeds, but also in delaying the herbicide resistance evolution in susceptible biotypes. Paswan *et al.* (2012) also suggested the rotation of herbicides and use of herbicide mixes as the two effective strategies to prevent buildup of herbicide resistance in weeds. Mixing up of herbicides with different modes of action bind different target sites of weeds and prevent the probability of target site resistance. Herbicide use for *Echinochloa crus-galli* control has a varying degree of success, depending upon the application method, combinations used, dose applied, and the time of application (Chauhan *et al.,* 2015)

Materials and methods

3. MATERIALS AND METHODS

The research programme was carried out during 2015-2017 to study the diversity of *Echinochloa* species and their response to common herbicides. The whole research work consisted of two parts:-

Part 1: Survey and morphological study of different species and types of *Echinochloa* in rice fields of Palakkad rice tract.

Part 2: Evaluation of efficacy of pre and post emergence herbicides on *Echinochloa* species by pot culture study.

3.1. Details of study area

The study was focused on the rice tracts of Palakkad district which included Chittur, Alathur, Kuzhalmannam, Kollengode, Nenmara and Palakkad. Seeds of the predominant species of *Echinochloa* were collected from Kuttanad and Kole rice tracts.

3.1.1. Palakkad rice tract

The area is located between the latitudes of 10°21' to 11°14' North, and longitudes of 76°02' to 76°45' East. The soil is laterite and low in available nitrogen, phosphorus, potassium and organic carbon. The pH of the soil is around 5. Rice is mainly grown under semi-dry situation in *Kharif* season, i.e., May-June to August-September. In *Rabi* season, i.e., September- October to December- January, the system followed is transplanted or irrigated rice under puddled condition, and depends on canal irrigation water from Mangalam, Pothundi and Malampuzha dams.

3.1.2. Kole lands

Kole lands are spread over Thrissur and Malappuram districts and cover over 13,000 ha. The area lies between the latitudes of 10°20' to 10°40' North, and longitudes of 75°58' to76°11' East and located 0.5 M to 1 M below mean sea level. The soil is clayey in texture with pH of around 5 and is high in organic carbon and available phosphorus, and medium in nitrogen and potassium. In Kole lands, rice is cultivated only in one season, i.e., September-October to February- March, and the land remains submerged for the rest of the year. However, in favorable locations, farmers raise a second crop during the period from February to April.

3.1.3. Kuttanad

Kuttanad refers to the high yielding rice tract located in Alleppey and Kottayam districts. The area is located at a latitude of 9°27' North and a longitude of 76°25' East and is around 0.5 to 2 metres below mean sea level. The soil texture is silty clay, with a pH of around 3.5 to 4.5. The soil is medium to high in organic carbon, available phosphorus and exchangeable potassium. In wetlands, rice is cultivated in two seasons, viz., May- June to September- October and November-December to March- April.

3.2. Climate and weather

Palakkad district, Kuttanad and Kole lands have tropical monsoon climate with more than 80 per cent of the rainfall distributed through south-west and north-east monsoon showers. The weather condition during the experimental period slightly deviated from the normal; there was a deficit of 33.7 per cent rain fall and high temperature (32-34 °C) during *Rabi* 2015-2017.

3.3. Experiments

3.3.1. Part 1: Survey and morphological study of different species and types of *Echinochloa* in rice fields of Palakkad rice tract.

Stratified surveys were conducted twice, the first one in the months of January and February, and the second in August and September of 2016 in key rice growing areas of Palakkad rice tracts. Ten locations were identified where different species or types of *Echinochloa* dominated. From each location, important morphological observations were recorded on 50 plants during the flowering stage. Observations on soil chemical properties, water management and weed management were also recorded. Seeds of different species and types were collected.

Seeds of dominant *Echinochloa* types were also collected from the rice tracts of Kuttanad and Kole lands to study the germination and efficacy of herbicides on these types.

Identification of *Echinochloa* species/ morphotypes

Plant samples collected from surveys were identified at the Botanical Survey of India, Southern Regional Centre, TNAU Campus, Coimbatore.

Observations

a) Morphological characters in the field

1. Plant height: Height of 50 plants from each location were measured from the base of the plant to the tip of the tallest leaf or panicle at the flowering stage and recorded in centimeters.
2. Number of tillers per plant: Total numbers of tillers per plant were counted after full heading. Observations were recorded from 50 plants in each location.

3. Number of panicles per plant: Number of panicles per tiller in a plant was recorded from 50 plants in each location.
4. Growth form: Growth form of the plant was recorded as erect or prostrate.
5. Leaf arrangement and size: Leaf arrangement of each type of *Echinochloa* was recorded and length and width of three leaves of each plant were recorded.
6. Presence or absence of awns: Recorded based on length as given in Table 1.
7. Flag leaf measurement: Length and width of the flag leaf (leaf just below the panicle) were recorded in centimetres.

Table 1. Awn character based on awn length

Sl. No.	Awn character	Awn length (mm)
1	Awnless	No awns
2	Short awned	0.1– 5
3	Long awned	>5

8. Panicle characters:
   a. Panicles were classified according to branching and angle of primary branches and distribution of spikelets as: a) compact, b) intermediate, and c) open
   b. Panicle length was recorded in centimetres from the base to the tip of the panicle
   c. Grain length: The grain length was recorded in millimetres.
   d. Grain width: The grain width at the widest point was recorded in millimetres.
   e. Awn length: The awn length was recorded from the tip of the grain to the tip of the awn in millimeters.
   f. Dry matter production: Plants in which heading had been completed were uprooted from the field and roots were washed thoroughly to remove soil particles. They were first air dried for three days and then

oven dried at 70± 5°C to constant weight. Dry weight was recorded in grams.

9. Weed frequency

$$\frac{\text{Number of sites where a particular weed species occurred X 100}}{\text{Total number of sites surveyed}}$$

10. Relative frequency

$$\frac{\text{Frequency of a species X 100}}{\text{Total number of frequencies of all species}}$$

b) Soil chemical properties and moisture status in the field

Soil samples were collected from each location and analysed in the laboratory. The methods used for physico-chemical analysis of soil are detailed in Table 2.

Table 2. Methods for soil physico-chemical analysis

Sl. No.	Soil property	Method used
1	pH	1: 2.5 soil water ratio Beckman glass electrode (Jackson, 1958)
2	Organic C (%)	Walkley and Black method (Jackson, 1958)
3	Available N (kg/ ha)	Alkaline permanganate method (Subbiah and Asija, 1956)
4	Available P (kg/ ha)	Bray-1 extractant ascorbic acid reductant method (Watnabe and Olsen, 1965)
5	Available K (kg/ ha)	Neutral normal ammonium acetate extractant flame photometry (Jackson, 1958)
6	Soil moisture status	Recorded as flooded/ saturated/ dry

c) Morphological characters in pot culture

1. Germination percentage

Germination studies on each type of *Echinochloa* were conducted in the laboratory. Seeds showing dormancy were subjected to various dormancy breaking treatments. For germination test, 10 seeds each were placed in petri dishes of 9 cm diameter lined with a piece of Whatman No.1 filter paper which had been moistened with distilled water. Seeds with a visible protrusion of radicle were considered to have germinated. The number of germinated seeds was counted at 15 days after sowing or until there was no further germination.

Treatments for breaking dormancy

- Hot water treatment: Seeds were dipped in boiling water for 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55 and 60 seconds before sowing.
- Ethanol + darkness + high temperature treatment: Seeds of all the four *Echinochloa* types were treated with different combinations of ethanol, pre-heating and light/darkness for 3 days, then transferred to light under normal room temperature after washing. The treatments included:
    1. Ethanol 0.5M + 36°C pre heating for 3 days + darkness
    2. Ethanol 0.5 M + darkness for 3 days
    3. Ethanol 1M + 36°C pre heating for 3 days + darkness
    4. Ethanol 1M + darkness for 3 days
    5. Distilled water + 36 °C + darkness for 3 days
    6. Control

2. Time to emergence: The time required for the shoot to reach the soil surface was recorded and indicated in days.

3. Heading time: The duration required for the panicle to become fully visible was recorded and indicated in days.

4. Growth duration: The duration from germination to final drying of plants was recorded and indicated in days.

3.3.2. Part 2: Evaluation of efficacy of pre and post emergence herbicides on *Echinochloa* species by pot culture study

a) Pre emergence herbicides

Efficacy of pre emergence herbicides was studied under both dry seeded and wet seeded conditions (Plate 11). Seeds were pre-treated with 1M ethanol under darkness for three days, washed in water and sown in earthen pots filled with soil. Each pot of diameter 50 cm was sown with 25 seeds. Separate experiments were conducted for the four different *Echinochloa* types with three replications for each treatment.

In dry seeded conditions, *Echinochloa* seeds were sown in pots filled with soil and irrigated lightly without flooding. Herbicides were sprayed on the day after sowing.

In wet seeded conditions, soil in the pots was puddled by hand and excess water removed after settling of the clay. Seeds were sown on the top layer and after one day again flooded to a depth of three centimetres. Water was drained after one day and herbicides were sprayed on the third day after sowing. Flooding was again done after 24 hours and continued for the duration of the study. The experimental design was CRD. The treatments are presented in Table 3.

b) Post emergence herbicides

Efficacies of post emergence herbicides were studied under wet seeded condition. The experimental design was CRD. Seeds were pre-treated with 1M ethanol under darkness for three days, washed with water and sown in pots. Each pot of diameter 50 cm was sown with 25 seeds. Separate experiments were conducted for different *Echinochloa* types with three replications for each treatment. Post emergent herbicides were sprayed twice, at four and eight leaf stages of the weed (Plate 12 & 13). The treatments are shown in Table 4.

Table 3. Pre emergence herbicide treatments

Sl. No.	Herbicide	Formulation	Dose (kg/ha)
T_1.	Pretilachlor	50 EC	0.75
T_2	Oxyfluorfen	23.5 EC	0.15
T_3	Pyrazosulfuron ethyl	10 WP	1.25
T_4	Pendimethalin	30 EC	1.50
T_5	Pretilachlor + Bensulfuron methyl	(0.60+ 0.06) WP	10 .0
T_6	Oxadiargyl	80 WP	0.10
T_7	Control	-	-

Table 4. Post emergence herbicide treatments

Sl. No.	Herbicide	Formulation	Dose (kg/ha)
T_1	Cyhalofop butyl	10 EC	0.080
T_2	Bispyribac sodium	10 EC	0.025
T_3	Penoxsulam	24 EC	0.025
T_4	Fenoxaprop–p–ethyl	6.9 EC	0.060
T_5	Ethoxysulfuron	15 WDG	0.015
T_6	Metamifop	10 EC	0.125
T_7	Control	-	-

Observations

Observations were recorded on:

1. Number of seedlings which emerged in each pot
2. Phytotoxicity symptoms of *Echinochloa* plants after spraying herbicides
3. Dry weight of remaining plants which survived the herbicide application

Based on the observations above, seedling survival percentage and weed persistence index were worked out as follows.

Seedling survival percentage =

$$\frac{\text{Number of seedlings survived after herbicide treatment} \times 100}{\text{Number of seedlings before herbicide treatment}}$$

Weed persistence index =

$$\frac{\text{Dry matter of weeds in treated plot}}{\text{Dry matter of weeds in control}} \times \frac{\text{Weed count in control}}{\text{Weed count in treated plot}}$$

(Mishra and Misra, 1987)

Statistical analysis

The data on seed germination percentage, seedling survival percentage and weed persistence index were transformed by angular transformation to normalize their distribution. They were then analysed following ANOVA, and the means were compared based on the critical differences (least significant difference) at 0.05 level of significance. The statistical software 'WASP 2.0 was used for doing analysis.

Phytotoxicity rating at two weeks after spraying

Effects of herbicides on weeds were done visually by taking into consideration weed kill, injury to weeds and growth reduction by each herbicide. The rating was done according to the toxicity scale of Thomas and Abraham (2007) as shown in Table 5.

Table 5. Response of weeds to herbicides

Rating	Effects on weeds
0	None
1	Slight
2	Moderate
3	Good control
4	Very good control
5	Complete control

N

$S_1R_2T_5$	$S_1R_3T_3$	Control	$S_1R_3T_4$	$S_1R_3T_6$	$S_1R_3T_2$	$S_1R_1T_4$
$S_1R_2T_1$	$S_1R_2T_6$	$S_1R_2T_3$	$S_1R_2T_2$	$S_1R_1T_1$	$S_1R_1T_6$	$S_1R_3T_5$
$S_1R_1T_3$	Control	$S_1R_3T_1$	$S_1R_1T_2$	$S_1R_2T_4$	$S_1R_1T_5$	Control

$S_2R_2T_6$	$S_2R_3T_6$	$S_2R_2T_1$	$S_2R_2T_5$	Control	$S_2R_2T_4$	$S_2R_1T_1$
$S_2R_1T_4$	Control	$S_2R_3T_1$	$S_2R_2T_2$	$S_2R_3T_5$	$S_2R_1T_5$	$S_2R_2T_3$
$S_2R_1T_6$	$S_2R_1T_3$	$S_2R_3T_3$	Control	$S_2R_3T_4$	$S_2R_1T_2$	$S_2R_3T_2$

$S_3R_2T_1$	$S_3R_2T_3$	$S_3R_2T_6$	Control	$S_3R_3T_2$	$S_3R_1T_5$	$S_3R_3T_4$
$S_3R_3T_5$	$S_3R_2T_2$	$S_3R_3T_1$	$S_3R_1T_2$	$S_3R_2T_5$	Control	$S_3R_1T_1$
Control	$S_3R_3T_3$	$S_3R_3T_6$	$S_3R_1T_6$	$S_3R_1T_3$	$S_3R_1T_4$	$S_3R_2T_4$

$S_4R_1T_3$	$S_4R_1T_1$	$S_4R_3T_3$	Control	$S_4R_1T_4$	$S_4R_3T_5$	$S_4R_3T_2$
$S_4R_2T_1$	$S_4R_2T_4$	Control	$S_4R_1T_5$	$S_4R_1T_2$	Control	$S_4R_3T_4$
$S_4R_2T_2$	$S_4R_3T_6$	$S_4R_2T_3$	$S_4R_2T_5$	$S_4R_1T_6$	$S_4R_2T_6$	$S_4R_3T_1$

Fig. 1. Layout of the experiment 'Efficacy of pre emergence herbicides in dry sown condition'

S_1- *Echinochloa colona*

S_2 - *Echinochloa crus-galli* (type A)

S_3 - *Echinochloa stagnina*

S_4 - *Echinochloa crus-galli* (type B)

T_1- Pretilachlor

T_2- Oxyfluorfen

T_3- Pyrazosulfuron ethyl

T_4- Pendimethalin

T_5- Pretilachlor + Bensulfuron methyl

T_6- Oxadiargyl

N

Control	Control	$S_4R_1T_4$	$S_4R_2T_5$	$S_4R_1T_6$	$S_4R_3T_1$	$S_4R_3T_5$
$S_4R_1T_3$	$S_4R_1T_1$	$S_4R_2T_1$	$S_4R_1T_5$	$S_4R_2T_6$	$S_4R_3T_6$	$S_4R_2T_3$
$S_4R_3T_2$	$S_4R_3T_4$	$S_4R_2T_2$	$S_4R_1T_2$	$S_4R_3T_3$	$S_4R_2T_4$	Control

$S_1R_1T_3$	$S_1R_2T_3$	Control	$S_1R_1T_1$	$S_1R_3T_4$	$S_1R_2T_4$	$S_1R_1T_5$
$S_1R_2T_2$	$S_1R_3T_1$	$S_1R_1T_6$	$S_1R_3T_5$	$S_1R_2T_5$	$S_1R_3T_3$	Control
$S_1R_2T_6$	Control	$S_1R_2T_1$	$S_1R_3T_2$	$S_1R_1T_2$	$S_1R_1T_4$	$S_1R_3T_6$

$S_3R_1T_5$	$S_3R_2T_1$	$S_3R_1T_6$	$S_3R_1T_4$	Control	$S_3R_3T_5$	$S_3R_1T_3$
$S_3R_2T_2$	$S_3R_1T_2$	$S_3R_3T_2$	$S_3R_3T_6$	$S_3R_3T_4$	$S_3R_2T_5$	$S_3R_3T_1$
Control	$S_3R_3T_3$	$S_3R_2T_4$	$S_3R_2T_3$	$S_3R_2T_6$	$S_3R_1T_1$	Control

$S_4R_3T_3$	Control	$S_4R_2T_1$	$S_4R_3T_6$	$S_4R_2T_2$	$S_4R_2T_5$	$S_4R_1T_2$
$S_4R_2T_4$	$S_4R_1T_5$	$S_4R_3T_4$	Control	$S_4R_1T_6$	$S_4R_2T_6$	$S_4R_1T_3$
Control	$S_4R_2T_3$	$S_4R_3T_1$	$S_4R_1T_1$	$S_4R_1T_4$	$S_4R_3T_5$	$S_4R_3T_2$

Fig. 2. Layout of the experiment 'Efficacy of pre emergence herbicides in puddle sown condition'

S_1- *Echinochloa colona*

S_2 - *Echinochloa crus-galli* (type A)

S_3 - *Echinochloa stagnina*

S_4 - *Echinochloa crus-galli* (type B)

T_1- Pretilachlor

T_2- Oxyfluorfen

T_3- Pyrazosulfuron ethyl

T_4- Pendimethalin

T_5- Pretilachlor + Bensulfuron methyl

T_6- Oxadiargyl

N

$S_4R_2T_1$	$S_4R_2T_3$	$S_4R_1T_1$	$S_4R_2T_4$	Control	$S_4R_3T_4$	$S_4R_3T_1$
$S_4R_1T_5$	Control	$S_4R_1T_6$	$S_4R_1T_3$	$S_4R_3T_3$	Control	$S_4R_2T_2$
$S_4R_1T_2$	$S_4R_2T_5$	$S_4R_2T_6$	$S_4R_3T_2$	$S_4R_1T_4$	$S_4R_3T_5$	$S_4R_3T_6$

$S_1R_1T_2$	$S_1R_1T_3$	Control	$S_1R_1T_4$	$S_1R_1T_5$	$S_1R_2T_3$	Control
$S_1R_3T_5$	$S_1R_3T_1$	$S_1R_1T_6$	$S_1R_2T_6$	$S_1R_3T_6$	$S_1R_3T_4$	$S_1R_2T_4$
$S_1R_1T_1$	Control	$S_1R_2T_1$	$S_1R_3T_2$	$S_1R_2T_2$	$S_1R_2T_5$	$S_1R_3T_3$

$S_3R_2T_6$	$S_3R_1T_3$	$S_3R_1T_5$	$S_3R_3T_3$	$S_3R_3T_2$	$S_3R_2T_1$	Control
$S_3R_1T_2$	$S_3R_2T_2$	$S_3R_2T_4$	$S_3R_1T_4$	$S_3R_3T_5$	$S_3R_3T_6$	$S_3R_3T_4$
Control	Control	$S_3R_2T_3$	$S_3R_2T_5$	$S_3R_3T_1$	$S_3R_1T_1$	$S_3R_1T_6$

$S_1R_1T_2$	$S_1R_3T_4$	$S_1R_3T_6$	$S_1R_3T_5$	$S_1R_1T_6$	Control	$S_1R_2T_3$
$S_1R_1T_4$	$S_1R_3T_2$	$S_1R_1T_3$	$S_1R_2T_4$	$S_1R_1T_5$	Control	$S_1R_3T_1$
$S_1R_3T_3$	Control	$S_1R_2T_5$	$S_1R_1T_1$	$S_1R_2T_1$	$S_1R_2T_2$	$S_1R_2T_6$

Fig. 3. Layout of the experiment 'Efficacy of post emergence herbicides – Four leaf stage'

S_1- *Echinochloa colona*

S_2 - *Echinochloa crus-galli* (type A)

S_3 - *Echinochloa stagnina*

S_4 - *Echinochloa crus-galli* (type B)

T_1- Cyhalofop butyl

T_2- Bispyribac sodium

T_3- Penoxsulam

T_4- Fenoxaprop-p-ethyl

T_5- Ethoxysulfuron

T_6- Metamifop

N

$S_2R_1T_4$	$S_2R_3T_4$	$S_2R_3T_1$	Control	$S_2R_2T_2$	$S_2R_3T_5$	$S_2R_1T_5$
$S_2R_1T_3$	Control	$S_2R_2T_3$	$S_2R_1T_2$	$S_2R_3T_2$	$S_2R_2T_6$	$S_2R_3T_6$
$S_2R_2T_1$	$S_2R_2T_5$	$S_2R_3T_3$	$S_2R_2T_4$	$S_2R_1T_1$	Control	$S_2R_1T_6$

$S_3R_3T_5$	$S_3R_2T_2$	$S_3R_3T_1$	$S_3R_1T_2$	$S_3R_2T_5$	$S_3R_1T_3$	$S_3R_1T_1$
Control	$S_3R_3T_2$	$S_3R_1T_5$	$S_3R_3T_4$	$S_3R_3T_3$	$S_3R_3T_6$	$S_3R_2T_4$
$S_3R_1T_4$	Control	Control	$S_3R_2T_1$	$S_3R_2T_3$	$S_3R_2T_6$	$S_3R_1T_6$

$S_4R_2T_1$	$S_4R_2T_4$	$S_4R_1T_1$	$S_4R_1T_5$	Control	$S_4R_2T_5$	$S_4R_3T_1$
$S_4R_1T_3$	$S_4R_2T_2$	$S_4R_3T_3$	$S_4R_2T_3$	$S_4R_1T_4$	$S_4R_3T_5$	$S_4R_3T_2$
$S_4R_1T_2$	$S_4R_3T_6$	$S_4R_3T_4$	Control	$S_4R_1T_6$	$S_4R_2T_6$	Control

$S_3R_2T_2$	$S_3R_2T_1$	$S_3R_1T_2$	$S_3R_2T_5$	$S_3R_3T_1$	$S_3R_3T_3$	$S_3R_3T_6$
Control	$S_3R_3T_2$	$S_3R_2T_3$	$S_3R_2T_6$	$S_3R_3T_5$	$S_3R_1T_3$	$S_3R_1T_1$
$S_3R_1T_4$	$S_3R_2T_4$	Control	$S_3R_1T_6$	Control	$S_3R_1T_5$	$S_3R_3T_4$

Fig. 4. Layout of the experiment 'Efficacy of post emergence herbicides – Eight leaf stage'

S_1- *Echinochloa colona*

S_2 - *Echinochloa crus-galli* (type A)

S_3 - *Echinochloa stagnina*

S_4 - *Echinochloa crus-galli* (type B)

T_1- Cyhalofop butyl

T_2- Bispyribac sodium

T_3- Penoxsulam

T_4- Fenoxaprop-p-ethyl

T_5- Ethoxysulfuron

T_6- Metamifop

Results

4. RESULTS

The results of the survey and pot culture study of the thesis work entitled 'The diversity of *Echinochloa* spp. and their response to select herbicides' are given in this chapter.

1. Part I: Survey and morphological study of different species and types of *Echinochloa* in rice fields of Palakkad rice tract

Two surveys were conducted in the main rice tracts of Palakkad district during the months of January and February, and August and September in 2016 and the areas having severe infestation of *Echinochloa* species were identified. Plate 1 shows locations covered in the district. Observations on morphological characters of the species of *Echinochloa* were taken from the areas having severe infestation (Plate 2). Matured seeds and five plant samples were collected from each location. Another survey was conducted in Moncombu (Alappuzha), a part of Kuttanad rice tract and Alappad area of the Kole lands of Thrissur in the months of December 2016 and January 2017. From areas of severe infestation of *Echinochloa* in the rice fields, seeds were collected from the predominant species (Plate 3). Soil samples from each location were also analysed in the laboratory.

1.1. Identification of species of *Echinochloa*

Four types of *Echinochloa* were obtained in the surveys. The collected panicle samples were identified at Botanical Survey of India, Southern Regional Centre located at T N A U Campus, Coimbatore (Plate 4). A copy of the certificate of Botanical Survey of India is attached as Appendix I

a) Map of Kerala showing the study locations

b) Locations in Palakkad from where *Echinochloa* spp. collected

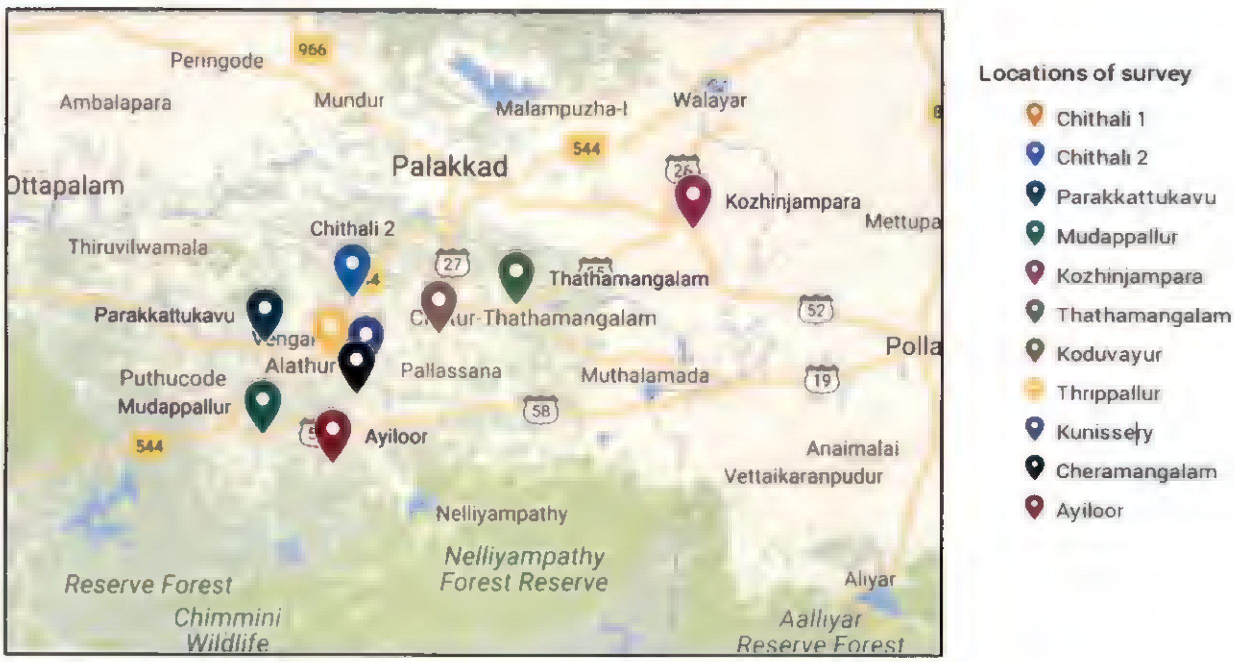


Plate 1. Location map of the study area



Plate 2. Survey at Palakkad rice tract


Kuttanadu (Moncombu)


Alappad Kole

Plate 3. Seed collection from Kuttanadu and Kole lands

The identified species of *Echinochloa* were:

1. *Echinochloa crus- galli* (L.) P. Beauv.

   This species consisted of two morphotypes, viz.,

   a) *Echinochloa crus- galli* (type A)

      Synonym: *Panicum crus-galli* L.

   b) *Echinochloa crus- galli* (type B)

      Synonyms: *Panicum crus-galli* L.

      Echinochloa glabrescens Munro ex Eggel.

      Echinochloa oryzoides auct non (Ard.) Fritsch

   Family: Poaceae

2. *Echinochloa picta* (J. Koenig) P. W. Michael

   Synonyms: *Panicum pictum* J. Koenig

   Echinochloa stagnina (Retz.) P. Beauv.

   Family: Poaceae

3. *Echinochloa colonum* (L.) Link

   Synonyms: *Panicum colonum* L.

   Echinochloa colona (L.) Link

   Family: Poaceae

Numerous synonyms exist for each species and type of *Echinochloa*. The most commonly used nomenclature in contemporary literature, viz. *E. colona, E. crus*-galli and *E. stagnina* were used for the species in the research programme. The two types of *E. crus-galli* which are distinctly different in morphology were designated as *E. crus-galli* (type A) and *E. crus-galli* (type B).

Plate 4. Types of *Echinochloa* obtained in survey

1.2. Distribution of *Echinochloa* species/ morphotypes

1.2.1. Palakkad rice tracts

Diverse *Echinochloa* species were distributed in the main paddy cultivating blocks of Palakkad district viz., Chittur, Alathur, Kuzhalmannam, Kollengode, and Nenmara. All the surveyed fields were under saturated moisture condition during August-September. The details of surveyed areas with severe infestation of *Echinochloa* and various *Echinochloa* species or morphotypes identified from each location are presented in Table 6. Chithali had severe infestation of three identified types, excluding *E. stagnina*. Parakkattukavu fields showed severe infestation of two types of *Echinochloa viz., E. colona* and *E. crus-galli* (type B) in the same field, whereas both types of *Echinochloa crus-galli* were present in Cheramangalam and Ayilur. Other common weeds identified in the surveyed fields were *Sacciolepis interrupta*, weedy rice *(Oryza sativa* f. *spontanea*), *Monochoria vaginalis, Ammania baccifera* and *Leptochloa chinensis*.

Another survey was also conducted through Varode, Amayur, Pallippuram, Pattambi, Parali, Mundur, Malambuzha and Palakkad with no infestation of *Echinochloa* species in the rice fallows. *Sacciolepis interrupta* was the dominant weed in these areas.

1.2.2. Kole lands

In Alappad Kole lands, three types of *Echinochloa* have been observed which included *E. crus-galli* (type A), *E. crus-galli* (type B) and *E. stagnina*. *E crus-galli* types were seen from the beginning of the crop season while *E. stagnina* was visible at the fag end. The field was flooded during the entire cropping period.

1.2.3. Kuttanad rice tracts

Echinochloa stagnina was the predominant type in the rice fields of Moncombu. The soil was in a flooded condition throughout the crop duration.

Table 6. Distribution of *Echinochloa* species/ morphotypes in surveyed areas

Sl. No.	Location	*Echinochloa* species/ morphotypes
1	Chithali 1	*Echinochloa colona*
2	Chithali 2	*Echinochloa crus-galli* (type A)
		Echinochloa crus-galli (type B)
3	Parakkattukavu	*Echinochloa crus-galli* (type B)
		Echinochloa colona
4	Modappallur	*Echinochloa colona*
5	Kozhinjampara	*Echinochloa crus-galli* (type A)
6	Thathamangalam	*Echinochloa crus-galli* (type A)
7	Koduvayur	*Echinochloa crus-galli* (type B)
8	Thrippalur	*Echinochloa colona*
9	Kunissery	*Echinochloa crus-galli* (type B)
10	Cheramangalam	*Echinochloa crus-galli* (type A)
		Echinochloa crus-galli (type B)
11	Ayilur	*Echinochloa crus-galli* (type A)
		Echinochloa crus-galli (type B)
12	Kuttanadu (Moncombu)	*Echinochloa stagnina*
13	Kole lands of Kerala (Alappad, Thrissur)	*Echinochloa crus-galli* (type A)
		Echinochloa crus-galli (type B)
		Echinochloa stagnina

1.2.4. Frequency and relative frequency of *Echinochloa* spp. in Palakkad rice tract

The frequency and relative frequency of *Echinochloa* distribution was highest for *E. crus-galli* (type B) followed by *E. crus- galli* (type A) and *E. colona*. (Table 7)

Table 7. Frequency and relative frequency of *Echinochloa* species/morphotypes in surveyed areas of Palakkad

Sl. No.	*Echinochloa* species/ Morphotype	Frequency (%)	Relative frequency (%)
1	*Echinochloa colona*	36.36	23.53
2	*Echinochloa crus-galli* (type A)	54.54	35.29
3	*Echinochloa crus-galli* (type B)	63.64	41.18

1.3. Morphological characters of *Echinochloa* species recorded in the field

Observations on morphological characters are given in the Table 8 and Table 9.

1.3.1. *Echinochloa colona*

Echinochloa colona is an annual grass with a lifespan of 95 – 120 days. In studies conducted in the laboratory, the seeds germinated within 3 – 5 days after sowing. The seeds of *Echinochloa colona* showed dormancy and recorded a germination percentage upto 70 under various dormancy breaking treatments. Heading started within 60 – 75 days after sowing. Plants grown in flooded condition flowered earlier than those grown under light irrigation.

Echinochloa colona samples thrived under a pH range of 4.4 -7.0. The plant was erect and height ranged from 53 – 186 cm. Young seedlings closely resembled rice seedlings but auricles and ligules were absent in *Echinochloa*. The recorded

Table 8. Morphological characters of *Echinochloa* spp. in the field

Sl. No.	*Echinochloa* species/ morphotypes	Location	No. of tillers/ plant	No. of panicles/ plant	Plant height (cm)	Growth form	Leaf arrangement	Leaf size		Flag leaf size		Dry weight (g/ plant)
								Length (cm)	Width (cm)	Length (cm)	Width (cm)	
1	*Echinochloa colona*	Chithali 1	4.40	7.48	139.02	Erect	Alternate-opposite	39.17	1.15	14.92	1.14	6.26
2		Parakkattukavu	2.76	2.08	83.44	-do-	-do-	36.56	1.00	14.50	0.80	5.32
3		Modappallur	3.06	3.80	114.96	-do-	-do-	37.49	1.10	15.95	1.03	7.68
4		Thrippalur	2.80	2.24	108.40	-do-	-do-	38.10	1.10	15.01	0.93	6.89
5	*Echinochloa crus-galli* (type A)	Chithali 2	8.70	4.90	168.50	-do-	-do-	34.71	1.00	20.4	1.10	7.48
6		Kozhinjampara	4.62	5.66	106.18	-do-	-do-	29.50	0.98	13.99	0.78	7.93
7		Thathamangalam	10.06	4.96	96.62	-do-	-do-	29.92	1.00	22.95	1.04	4.98
8		Cheramangalam	2.67	2.03	105.34	-do-	-do-	31.42	1.00	17.99	1.22	6.02
9		Ayilur	1.75	1.80	149.05	-do-	-do-	39.90	1.24	16.73	1.03	7.69
10		Kole lands (Alappad, Thrissur)	1.62	1.35	113.73	-do-	-do-	31.94	0.94	15.49	0.93	5.26

Table 8. Morphological characters of *Echinochloa* spp. in the field (contd...)

Sl. No.	*Echinochloa* species/ morphotypes	Location	No. of tillers/ plant	No. of panicles/ plant	Plant height (cm)	Growth form	Leaf arrangement	Leaf size		Flag leaf size		Dry weight (g/ plant)
								Length (cm)	Width (cm)	Length (cm)	Width (cm)	
11	*Echinochloa crus-galli* (type B)	Chithali 2	2.98	1.06	94.56	-do-	-do-	35.00	0.97	18.05	0.93	4.86
12		Parakkattukavu	2.48	1.90	76.72	-do-	-do-	32.57	0.93	13.67	0.81	5.53
13		Koduvayur	2.58	1.62	105.78	-do-	-do-	34.76	1.10	17.80	0.93	5.03
14		Kunissery	3.68	3.52	115.80	-do-	-do-	36.38	1.13	16.83	0.89	7.84
15		Cheramangalam	3.24	2.93	103.76	-do-	-do-	38.43	1.18	16.80	0.99	7.72
16		Ayilur	1.92	1.36	122.64	-do-	-do-	35.76	1.01	16.70	0.92	5.83
17		Kole lands (Alappad, Thrissur)	1.36	1.23	121.84	-do-	-do-	40.20	1.21	16.69	0.93	5.64
18	*Echinochloa stagnina*	Kuttanadu (Moncombu)	1.40	1.60	187.32	Prostrate to erect	-do-	30.83	0.87	14.83	0.83	3.97
19		Kole lands (Alappad, Thrissur)	1.90	2.10	193.62	-do-	-do-	31.48	0.83	15.45	0.87	4.16

Table 9. Panicle characters (mean) of *Echinochloa* species/ morphotypes

Sl. No.	*Echinochloa* species/ Morphotype	Panicle length (cm)	No. of branches/ panicle	No. of spikelet/ panicle	Spikelet length (mm)	Spikelet width (mm)	Awn length (mm)	Awn character	Spikelet colour
1	*Echinochloa colona*	33.46	17.40	371.10	3.45	1.60	0.00	Awn less	Green to purple
2	*Echinochloa crus-galli* (type A)	38.97	18.70	487.70	4.70	1.75	1.50	Short awned	Green to purple
3	*Echinochloa crus-galli* (type B)	36.03	18.00	403.00	14.75	1.90	11.00	Long awned	Green to purple
4	*Echinochloa stagnina*	41.13	7.00	83.10	14.35	2.00	9.00	Long awned	Green to purple

Table 10. Phenophases of *Echinochloa* species/ morphotypes

Sl. No.	*Echinochloa* species/ morphotype	Days to emergence	Days to heading	Total duration
1	*Echinochloa colona*	3-5 days	65-75 days	95-120 days
2	*Echinochloa crus-galli* (type A)	3-7 days	50-60 days	90-120 days
3	*Echinochloa crus-galli* (type B)	2-4 days	70- 95 days	120-125 days
4	*Echinochloa stagnina*	3-7 days	55- 60 days	Perennial

a) *E. colona* – habit

b) Tiller production in *E. colona*

c) Panicle of *E. colona*

Plate 5. *Echinochloa colona*

number of tillers per plant varied from 1- 17 and the number of panicles per plant ranged from 1-18. Stem was greenish in colour with stout, erect, ascending culm often showing branching from the base. Leaves were light green in colour with alternate – opposite phyllotaxy. The size of the leaves varied with the crop ecosystem and the average length and width of the leaf were 38.83 cm and 1.09 cm respectively. The dry matter production of the fully matured plant collected from different location ranged from 5.32 to 7.68 g/ plant.

The panicle was erect with 10 – 40 cm length. Panicles were either loose or compact and the average number of branches per panicle was 17 and average number of spikelets per panicle was 371. The average seed production rate of the plant was 1447 per plant. Spikelets were awnless and greenish or purplish in colour. Spikelets were broadly ovate. The spikelets had an average length of 3.45 mm and an average width of 1.60 mm. The close view of the plant is given in the Plate 5.

1.3.2. *Echinochloa crus-galli* (type A)

Echinochloa crus-galli (type A) had a life span of 90 – 120 days. The seeds germinated within 3 -7 days in the laboratory. The seeds possessed dormancy and recorded a maximum germination per cent of 40 under various dormancy breaking treatments. The time taken for heading ranged from 50 – 60 days.

The plants grew under a wide pH range of 4.41 in Chithali to 7.76 in Kozhinjampara. The growth form was erect with a plant height of 76 – 195 cm. They resembled rice seedlings but auricles and ligules were absent. The tiller number varied from 1 – 21 and the number of panicles per plant ranged from 1-21. The stem and leaf characters were similar to that of *Echinochloa colona*. The leaf length varied from 20 – 40 cm with leaf width of 0.8 – 1.5 cm. The dry matter production of plants collected from different locations had a range of 4.98 – 7.93 g/ plant.

a) *E. crus-galli* (type A) – Habit

b) Tiller production in *E. crus-galli* (type A)

c) Panicle of *E. crus-galli* (type A)

Plate 6. *Echinochloa crus-galli* (type A)

The panicle was erect, often more compact than *Echinochloa colona* with a length of 20-50 cm. The average number of branches per panicle was 19 and average number of spikelets per panicle was 488. The average seed production potential of *E. crus-galli* (type A) was 1683 seeds/ plant. The spikelets were purplish or green in colour with small awns. Awn length varied with the plant, and often the spikelets at the tip of the panicle or panicle branch had the longest awns and the awn length ranged upto 3 mm. The average awn length of the spikelets was 1.50 mm. The average size of the spikelet was 4.7 x 1.75 mm (length and width). Image of the plant is given in Plate 6.

1.3.3. *Echinochloa crus-galli* (type B)

Echinochloa crus-galli (type B) took more than 120 days to complete its life span. In the laboratory, the seeds germinated within 2 – 4 days after sowing. This morphotype had a seed germination percentage upto 90 without any seed dormancy. The plant took 70 – 95 days for heading, after sowing.

The plants could be seen in soils with a pH ranging from 4.46 in Chithali to 6.49 in Koduvayur. The growth form, seedlings, stems characters, leaf characters and leaf arrangement were similar to that of *E. crus-galli* (type A). The plants grew upto a height of 46 – 191 cm. Tillering ability varied from 1 – 9 per plant and the number of panicles per plant ranged from 1 – 9. The size of the leaf ranged from 22 – 50 cm length and 0.8 – 1.5 cm width. The dry matter production per plant ranged from 4.86 to 7.84 g at mature stage.

The panicle was erect, and was loosely to tightly packed. The panicle length ranged from 25 – 45 cm with an average of 18 branches per panicle. The average number of spikelets per panicle was 403, and the average seed production potential of the plant was 746 seeds per plant. The spikelets were green to purple with long awns. The length of the awn ranged from 6 – 13.5 mm. The spikelets had average dimensions of 14.75 mm length (including awn) and 1.90 mm width. Image of the plant is given in Plate 7.

a) *E. crus-galli* (type B) - Habit

b) Tiller production in *E. crus-galli* (type B)

c) Panicle of *E. crus-galli* (type B)

Plate 7. *Echinochloa crus-galli* (type B)

1.3.4. *Echinochloa stagnina*

Echinochloa stagnina is a perennial plant growing upto a height of 53- 210 cm. The seeds germinated within 3-7 days after sowing in pots. The seeds exhibited deep dormancy. Seed germination percentage was very poor. However seed germination was improved upto 50 per cent by soaking in ethanol (1M) under darkness for 3 days. Heading began 55-60 days after sowing.

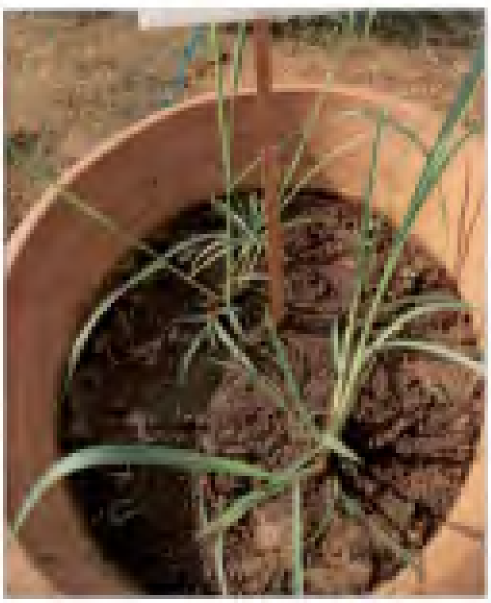
E. stagnina was found growing in soils with pH ranging of 5.1 to 6.9. The growth form was prostrate to erect. Vegetative propagation was also possible by stolons. In rice fields, the tiller number ranged from 1 to 3, whereas in pots, the tiller number exceeded 12. As it is a perennial plant, the number of panicles ranged from 1 to more than 15 per plant. The stem was erect, ascending with branching at the base. The stem was more cylindrical than other *Echinochloa* spp. Leaves were dark green with a prominent midrib. The size of the leaves ranged from 15 – 35 cm length and 0.5 – 0.9 cm width. The dry weight at flowering stage ranged from 3.97 to 4.16 g/ plant.

The panicle was erect and loosely packed. Panicle length ranged from 35 – 52 cm with an average of 7 branches per panicle. The average number of spikelets per panicle was 83.1 and the average seed production potential of the plant in rice field in a season was 162. Close view of the plant is given in the Plate 8.

1.4. Soil chemical properties and moisture level in the field

The surveyed areas had a pH range of 4.41 to 7.76 with dominating acidic pH. Ten locations had higher level of organic carbon percentage out of the 13 survey locations and the remaining areas had moderate level of organic carbon percentage. Available nitrogen content in the soil of different locations ranged from low to high levels; 5 locations had high, 7 locations had moderate and 1 location had low nitrogen content. The range of available phosphorus content was high in 4 locations, whereas 6 locations had moderate and 3 locations had low phosphorus content. In

a) *E. stagnina* - Habit



b) Tiller production in *E. stagnina*

c) Panicle of *E. stagnina*

Plate 8. *Echinochloa stagnina*

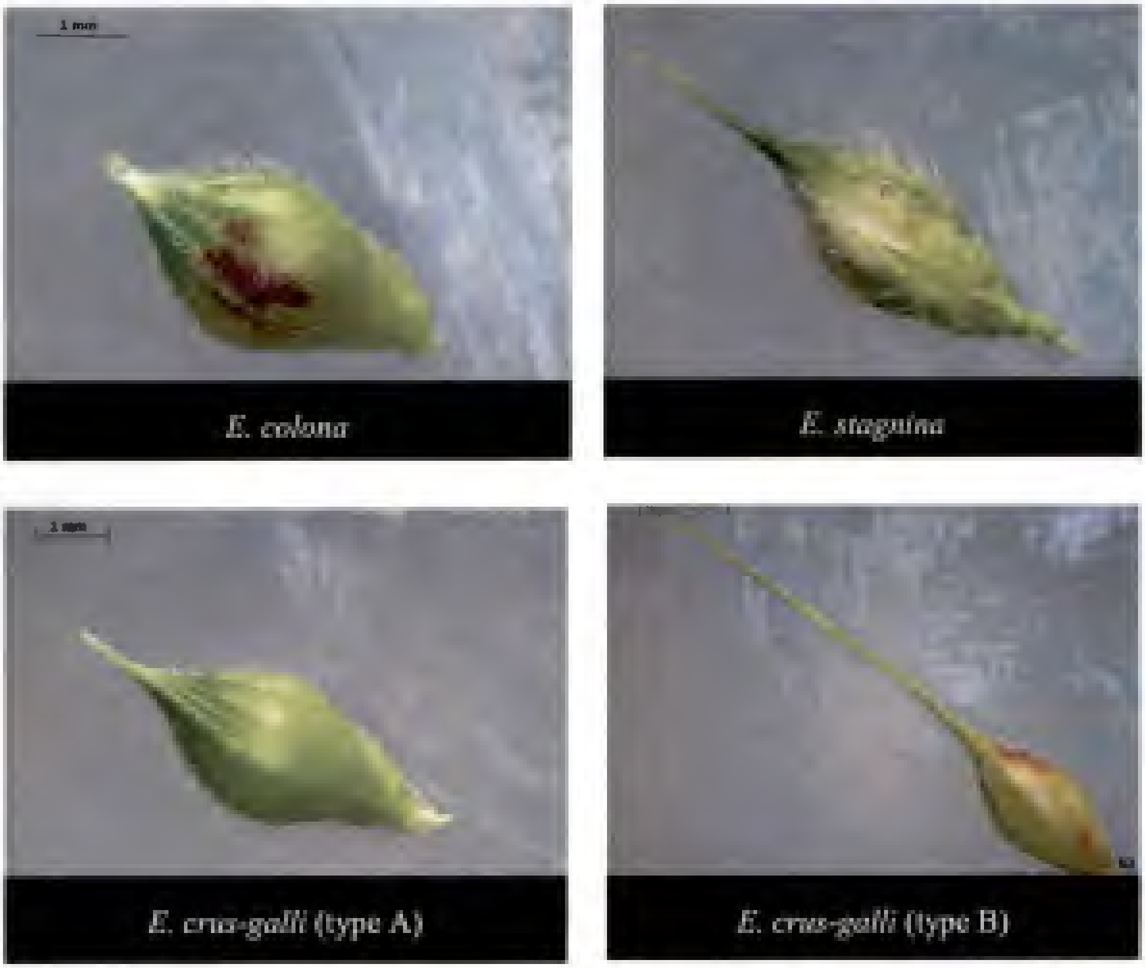


Plate 9. Spikelets of *Echinochloa* spp.

Plate 10. Length and distribution of awns on the spikelets of *E. crus-galli* types.

the case of available potassium content, 6 locations had low levels, 5 locations had moderate levels and 2 locations had high levels. The soil was saturated in all locations except in Alappad kole land and Moncombu of Kuttanad where it was flooded (Table 11).

Among the survey locations from where *Echinochloa colona* was identified, 75 per cent of the locations had high organic carbon per cent, and phosphorus and potassium content were also moderate in 75 per cent of the soil samples analyzed. Available nitrogen content was high in 50 per cent of the locations and the remaining 50 per cent was moderate in nitrogen content.

Among the locations from where *Echinochloa crus-galli* (type A) was collected, 66.7 per cent had high organic carbon content. The N, P and K content of the locations ranged from low to high. 50 per cent of the locations were moderate in nitrogen content, 66 per cent were high in phosphorus content and 50 per cent locations were low in potassium content.

Echinochloa crus-galli (type B) was seen in locations having high organic carbon content (71.43 % of surveyed areas), whereas the nitrogen content varied from low to high. Moderate nitrogen content was recorded in 71.4 per cent of the locations. Phosphorus content ranged from moderate to high, and 57.14 per cent of the locations were moderate in phosphorus. Potassium content had a range of low to high with 57 per cent of the locations having low potassium content.

Echinochloa stagnina was present in soils of high organic carbon per cent. Available nitrogen content was low in Kole lands and high in Moncombu whereas phosphorus contents in these areas were moderate and low with potassium contents high and moderate respectively.

Table 11. Soil chemical properties and moisture level in the field

Sl. No	Location	Soil pH	Organic C (%)	Available N (kg/ ha)	Available P (kg/ ha)	Available K (kg/ ha)	Soil moisture level
1	Chithali 1	4.41	0.76	501.76	20.00	142.20	Saturated
2	Chithali 2	4.46	0.80	627.20	32.17	84.00	Saturated
3	Parakkattukavu	6.41	0.74	376.30	17.96	142.24	Saturated
4	Modappallur	4.74	0.93	689.90	12.95	152.30	Saturated
5	Kozhinjampara	7.76	1.17	439.04	03.34	84.00	Saturated
6	Thathamangalam	6.28	0.62	627.20	23.40	227.33	Saturated
7	Koduvayur	6.49	0.78	439.04	12.53	108.60	Saturated
8	Thrippalur	6.02	0.81	376.02	10.03	67.20	Saturated
9	Kunissery	5.40	0.77	439.04	21.31	99.68	Saturated
10	Cheramangalam	4.85	0.87	376.00	44.29	113.12	Saturated
11	Ayilur	6.00	0.71	439.04	130.80	381.92	Saturated
12	Moncombu (Kuttanadu)	5.10	4.10	1317.12	9.19	208.32	Flooded
13	Alappad Kole (Thrissur)	5.02	2.23	268.12	20.86	385	Flooded

1.5. Seed treatments to break dormancy

All the species of *Echinochloa* exhibited dormancy in varying degrees. The duration of storage of the seeds had no discernible effect on the germination of the seeds, and an erratic pattern of germination was observed (Table 12.). Two treatments were tried to break dormancy and improve germination of *Echinochloa*, viz., hot water treatments and ethanol treatments.

On treating with hot water, higher germination percentage was obtained when seed was soaked in boiling water for 45 seconds (Table 13.).

Ethanol treatment was found to be most effective in enhancing germination rate of *Echinochloa* spp. Pre-soaking of seeds of all the four types for three days in 1M ethanol under darkness was the best treatment; 80 per cent germination was recorded in *E. crus-galli* (type B) and 65 per cent in *E. colona* while the other two types recorded a germination of 35 per cent each (Table 14). This treatment was therefore applied in the subsequent pot culture experiments. Among the four types, *E. crus-galli* (type B) exhibited the least dormancy, with untreated control recording 75 per cent germination. All the other types required seed treatment for germination. *E. stagnina* was the least amenable to seed treatment and recorded the lowest germination (Table 14.)

Table 12. Effect of storage period on seed germination

Days after Harvesting of seeds	Germination (%)
10	30
20	40
30	20
40	40
50	30
60	10
70	0
80	50
90	30
100	0
110	10
120	0

Table 13. Effect of hot water treatment on seed germination

Duration of exposure (s)	Germination (%)
5	0
10	0
15	0
20	0
25	10
30	50
35	50
40	30
45	60
50	30
55	30
60	50

Table 14. Ethanol treatment to break dormancy of *Echinochloa* species/ morphotypes

Sl. No.	Treatments	*Echinochloa* species/ morphotypes				
		Echinochloa colona	*Echinochloa crus-galli* (type A)	*Echinochloa crus-galli* (type B)	*Echinochloa stagnina*	Mean
1	Ethanol 0.5M + 36^{0}C heating + darkness for 3 days	*29.92 (25.00)	26.56 (20.00)	65.61 (82.50)	10.56 (5.00)	33.17
2	Ethanol 0.5 M + darkness for 3 days	22.59 (15.00)	22.04 (20.00)	47.88 (55.00)	0.34 (0.00)	23.21
3	Ethanol 1 M+ 36 ^{0}C heating + darkness for 3 days	60.07 (75.00)	33.21 (30.00)	60.08 (75.00)	29.92 (25.00)	45.82
4	Ethanol 1 M+ darkness for 3 days	53.76 (65.00)	36.24 (35.00)	63.43 (80.00)	35.94 (35.00)	47.34
5	Distilled water + 36 ^{0}C heating + darkness for 3 days	35.94 (35.00)	0.34 (0.00)	51.14 (51.31)	0.34 (0.00)	21.94
6	Control	0.34 (0.00)	0.34 (0.00)	60.07 (75.00)	0.34 (0.00)	15.27
	Mean	33.77	19.79	58.04	12.91	
CD (0.05) – treatments – 5.21						
CD (0.05) – *Echinochloa* species – 4.25						
CD (0.05) – interaction treatments X *Echinochloa* species – 10.42						

*Angular transformed values, original value in parenthesis.

2. Part II. Evaluation of efficacy of pre and post emergence herbicides on *Echinochloa* spp. by pot culture study

2.1. Efficacy of pre-emergence herbicides on *Echinochloa* spp.

Pre-emergence herbicides were applied in pots seeded with four types of *Echinochloa* in both dry (simulating dry seeded) and puddled (simulating wet seeded) condition (Plate 11). There was no seed germination in pots treated with pretilachlor, oxyfluorfen, pendimethalin, ethoxysulfuron, and oxadiargyl in both puddle sown and dry sown conditions. These pre-emergence herbicides were thus 100 per cent efficient in controlling all the four types of *Echinochloa*. However, in pots treated with pyrazosulfuron-ethyl, both seed germination and seedling emergence was observed in three types of *Echinochloa*. There was no germination of *E. stagnina* in drained and puddle condition treated with pyrazosulfuron-ethyl. However, plants grown in dry sown condition were more susceptible to pyrazosulfuron-ethyl than those in wet sown condition, registering less germination and emergence of *E. stagnina*. The susceptibility to pyrazosulfuron-ethyl was in the order;

E. stagnina> *E. crus-galli* A > *E. colona* > *E. crus-galli* B (Table 15)

Table 15. Efficacy of pyrazosulfuron-ethyl on species of *Echinochloa*

Sl. No	Species of *Echinochloa*	Treatments	Puddle sown		Drained sown	
			Germination (%)	WCE (%)	Germination (%)	WCE (%)
1	*E. colona*	Pyrazosulfuron-ethyl	36.00	14.29	4.00	87.50
		Control	42.00		32.00	
2	*E. crus-galli* (type A)	Pyrazosulfuron-ethyl	5.33	82.62	1.33	95.25
		Control	30.67		28.00	
3	*E. crus-galli* (type B)	Pyrazosulfuron-ethyl	49.33	7.50	20.00	59.46
		Control	53.33		49.33	
4	*E. stagnina*	Pyrazosulfuron-ethyl	2.67	88.00	0.00	100.00
		Control	22.67		20	

a) General view of the experimental plot

b) Dry sown condition

c) Puddle sown condition

Plate 11. Field view of the experiment 'Efficacy of pre emergence herbicides on *Echinochloa* spp.'

2.2. Efficacy of post-emergence herbicides on *Echinochloa* spp.

2.2.1. Effect of post emergence herbicides on seedling survival of the species of *Echinochloa*

No seedlings of *E. colona* survived with bispyribac sodium, penoxsulam and metamifop applied at four leaf stage and these were significantly better than the other herbicide treatments. On the other hand, all the seedlings survived by ethoxysulfuron treated at both four and eight leaf stages and cyhalofop butyl treated at eight leaf stage. Cyhalofop butyl was also seen to be less effective in killing *E. colona* at four leaf stage, registering a survival percentage of 62 (Table 15).

Bispyribac sodium applied at eight leaf stage of *E. crus-galli* (type A) had zero seedling survival and it was significantly lower than that of the other herbicide treatments, whereas all the seedlings survived for cyhalofop butyl and ethoxysulfuron applied at eight leaf stage, and these herbicides were equally ineffective at four leaf stage also. Metamifop and penoxsulam application resulted in more than 50 per cent death of *E. crus-galli* (type A) seedlings when applied at both four leaf and eight leaf stages. Fenoxaprop-p-ethyl was found to be less effective, with 65 per cent and 59 per cent of the seedlings surviving when applied at the four leaf and eight leaf stages respectively (Table 16).

For *E. crus-galli* (type B), seedling survival was zero when metamifop was applied at four leaf stage and penoxsulam applied at eight leaf stage. These treatments were on par with metamifop applied at eight leaf stage and fenoxaprop-p-ethyl at four leaf stage. Seedling survival was 100 per cent in ethoxysulfuron and cyhalofop butyl applied at eight leaf stage and they were on par with the same herbicides when applied at four leaf stage. At four leaf stage also, penoxsulam application was quite effective, killing 86 per cent of *E. crus-galli* (type B) seedlings. Bispyribac sodium was less effective, recording survival percentage of 47.6 and 85.5 at the two stages (Table 17).

Plate 12. Field view of the experiment 'Efficacy of post emergence herbicides on *Echinochloa* spp.at four leaf stage'

Plate 13. Field view of the experiment 'Efficacy of post emergence herbicides on *Echinochloa* spp. at eight leaf stage'

Table 16. Effect of herbicides on seedling survival (%) of *E. colona*

Sl. No.	Treatments	Stage of application	
		Four leaf	Eight leaf
1	Cyhalofop butyl	*62.64 (78.57)	89.52 (100.00)
2	Bispyribac sodium	0.48 (0.00)	31.62 (27.84)
3	Penoxsulam	0.48 (0.00)	72.94 (87.50)
4	Fenoxaprop-p-ethyl	64.84 (75.00)	38.97 (39.70)
5	Ethoxysulfuron	89.52 (100.00)	89.52 (100.00)
6	Metamifop	0.48 (0.00)	34.76 (33.30)
	C.D. (0.05)	15.02	

Table 17. Effect of herbicides on seedling survival (%) of *E. crus-galli* (A)

Sl. No.	Treatments	Stage of application	
		Four leaf	Eight leaf
1	Cyhalofop butyl	*79.39 (95.00)	89.52 (100.00)
2	Bispyribac sodium	34.79 (33.33)	0.48 (0.00)
3	Penoxsulam	44.27 (48.75)	35.53 (41.66)
4	Fenoxaprop-p-ethyl	54.06 (65.00)	50.38 (59.33)
5	Ethoxysulfuron	72.46 (86.64)	89.52 (100.00)
6	Metamifop	38.30 (38.63)	42.95 (46.42)
	C.D. (0.05)	27.36	

*Angular transformed values. Original values in parenthesis

Table 18. Effect of herbicides on seedling survival (%) of *E. crus-galli* (type B)

Sl. No.	Treatments	Stage of application	
		Four leaf	Eight leaf
1	Cyhalofop butyl	*79.89 (95.45)	89.52 (100.00)
2	Bispyribac sodium	43.56 (47.62)	67.78 (85.70)
3	Penoxsulam	18.33 (14.28)	0.48 (0.00)
4	Fenoxaprop-p-ethyl	10.61 (5.00)	42.12 (45.00)
5	Ethoxysulfuron	78.11 (93.75)	89.52 (100.00)
6	Metamifop	0.48 (0.00)	11.89 (6.25)
	C.D. (0.05)	13.54	

Table 19. Effect of herbicides on seedling survival (%) of *E. stagnina*

Sl. No.	Treatments	Stage of application	
		Four leaf	Eight leaf
1	Cyhalofop butyl	*47.88 (55.00)	89.52 (100.00)
2	Bispyribac sodium	61.71 (77.50)	61.85 (70.00)
3	Penoxsulam	61.85 (70.00)	38.86 (40.00)
4	Fenoxaprop-p-ethyl	22.09 (20.00)	59.84 (66.66)
5	Ethoxysulfuron	72.94 (87.50)	89.52 (100.00)
6	Metamifop	45.00 (50.00)	31.62 (35.71)
	C.D. (0.05)	29.61	

*Angular transformed values. Original values in parenthesis

The best treatment with the lower seedling survival for *E. stagnina* was fenoxaprop-p-ethyl applied at four leaf stage (20 per cent). It was on par with metamifop applied at four and eight leaf stages and penoxsulam at eight leaf stage. Seedling survival was 100 per cent with ethoxysulfuron and cyhalofop butyl applied at eight leaf stage. It was on par with bispyribac sodium at four and eight leaf stages, penoxsulam and ethoxysulfuron at four leaf stages. Cyhalofop butyl applied at four leaf stage resulted in better kill (45 per cent) of *E. stagnina* seedlings (Table 18).

2.2.2. Effects of post emergence herbicides on weed persistence index (WPI) of the species of *Echinochloa*

Weed persistence index was calculated based on the number of seedlings which survived and their dry matter production one month after application.

Weed persistence index of *E. colona* was zero for penoxsulam, bispyribac sodium and metamifop applied at four leaf stage as there was no seedling survival. It was the highest for ethoxysulfuron applied at the eight leaf stage, and was on par with cyhalofop butyl applied at the four leaf stage and fenoxaprop-p-ethyl applied at the eight leaf stage. Application of ethoxysulfuron at the four leaf stage and cyhalofop butyl applied at the eight leaf stage also resulted in high weed persistence indices (Table 19).

For *E. crus-galli* (type A), WPI was zero with bispyribac sodium applied at the eight leaf stage and the treatment was on par with all the other herbicides applied at the four leaf stage, excluding metamifop. The highest WPI was recorded in ethoxysulfuron applied at the eight leaf stage, and this was on par with cyhalofop butyl and fenoxaprop-p-ethyl applied at the eight leaf stage. Penoxsulam applied at the eight leaf stage recorded a comparatively low WPI of 0.25 (Table 20).

WPI of *E. crus-galli* (type B) was zero for metamifop applied at the four leaf stage and penoxsulam applied at the eight leaf stage, and these treatments were on par with fenoxaprop-p-ethyl and penoxsulam applied at the four leaf stage.

Ethoxysulfuron applied at the eight leaf stage recorded highest WPI and was on par with cyhalofop butyl applied at the eight leaf stage. At the eight leaf stage, after penoxsulam, metamifop and fenoxaprop-p-ethyl were the best recording WPIs of 0.14 and 0.21 respectively (Table 21).

E. stagnina recorded the lowest WPI for the treatment fenoxaprop-p-ethyl applied at the four leaf stage, which was on par with metamifop applied at the eight leaf stage. The highest WPI was for ethoxysulfuron applied at the eight leaf stage and was on par with all the other herbicides which were applied at the eight leaf stage excluding metamifop, and also with cyhalofop butyl and ethoxysulfuron applied at the four leaf stage. After fenoxaprop-p-ethyl, the best treatments at the four leaf stage of *E. stagnina* were penoxsulam, bispyribac sodium, and metamifop which recorded WPI values of 0.44, 0.45 and 0.47 respectively (Table 22).

Table 20. Effects of herbicides on WPI of *E. colona*

Sl. No.	Treatments	Stage of application	
		Four leaf	Eight leaf
1	Cyhalofop butyl	*5.03 (0.77)	4.98 (0.75)
2	Bispyribac sodium	0.48 (0.00)	3.89 (0.48)
3	Penoxsulam	0.48 (0.00)	2.53 (0.19)
4	Fenoxaprop-p-ethyl	1.51 (0.08)	5.56 (0.94)
5	Ethoxysulfuron	4.74 (0.63)	5.68 (0.99)
6	Metamifop	0.48 (0.00)	2.28 (0.16)
	C.D. (0.05)	0.65	

Table 21. Effects of herbicides on WPI of *E. crus-galli* (type A)

Sl. No.	Treatments	Stage of application	
		Four leaf	Eight leaf
1	Cyhalofop butyl	*1.48 (0.06)	5.28 (0.85)
2	Bispyribac sodium	1.09 (0.04)	0.48 (0.00)
3	Penoxsulam	1.22 (0.05)	2.50 (0.25)
4	Fenoxaprop-p-ethyl	0.92 (0.02)	4.55 (0.63)
5	Ethoxysulfuron	1.61 (0.08)	5.30 (0.86)
6	Metamifop	2.38 (0.17)	3.44 (0.41)
	C.D. (0.05)	1.23	

*Angular transformed values. Original values in parenthesis

Table 22. Effects of herbicides on WPI of *E. crus-galli* (type B)

Sl. No.	Treatments	Stage of application	
		Four leaf	Eight leaf
1	Cyhalofop butyl	*3.89 (0.48)	4.45 (0.61)
2	Bispyribac sodium	3.42 (0.36)	3.25 (0.32)
3	Penoxsulam	1.71 (0.11)	0.48 (0.00)
4	Fenoxaprop-p-ethyl	1.34 (0.08)	2.59 (0.21)
5	Ethoxysulfuron	2.97 (0.17)	5.35 (0.87)
6	Metamifop	0.48 (0.00)	1.90 (0.14)
	C.D. (0.05)	1.23	

Table 23. Effects of herbicides on WPI of *E. stagnina*

Sl. No.	Treatments	Stage of application	
		Four leaf	Eight leaf
1	Cyhalofop butyl	*4.58 (0.64)	5.26 (0.84)
2	Bispyribac sodium	3.83 (0.45)	4.42 (0.59)
3	Penoxsulam	3.78 (0.44)	4.66 (0.66)
4	Fenoxaprop-p-ethyl	2.18 (0.19)	4.22 (0.54)
5	Ethoxysulfuron	4.20 (0.54)	5.63 (0.96)
6	Metamifop	3.95 (0.47)	3.23 (0.44)
	C.D. (0.05)	1.54	

*Angular transformed values. Original values in parenthesis

2.2.3. Phytotoxicity rating at two weeks after spraying

Phytotoxicity rating was done at two weeks after spraying of herbicides as per the toxicity scale of Thomas and Abraham (2007) and the injury symptoms were graded from 0-5 (Table 23).

Among the tested herbicides, bispyribac sodium, penoxsulam and metamifop provided complete control of some species of *Echinochloa*. For bispyribac sodium, the first symptom was slight yellowing and complete rotting on the seventh day after spraying. For penoxsulam, the plants started showing symptoms such as yellowing and gradual drying within ten days after planting. Complete drying of plants occurred within ten days after spraying in the case of metamifop. Fenoxaprop-p-ethyl gave good to very good control against all the four species. The symptoms, such as yellowing and burning of the leaves from the tip downwards of the leaf lamina, started within ten days. Cyhalofop butyl exhibited slight to moderate injury in various species with a whitish band emerging on the leaf blades from which point the leaf began to wither. This particular symptom started four days after spraying and there were no other further symptoms. Ethoxysulfuron did not show any phytotoxicity symptoms on the plants.

Table 24. Phytotoxicity rating at two weeks after spraying

Sl. No.	Treatments	*E. colona*	*E. crus-galli* (type A)	*E. crus-galli* (type B)	*E. stagnina*
1	Cyhalofop butyl	1	2	2	2
2	Bispyribac sodium	5	5	5	3
3	Penoxsulam	5	4	5	2
4	Fenoxa prop-p-ethyl	4	3	4	4
5	Ethoxysulfuron	0	0	0	0
6	Metamifop	5	4	5	3

Discussion

4. DISCUSSION

The results obtained from the survey and pot culture study conducted as part of the thesis programme entitled 'Diversity of *Echinochloa* spp. and their response to select herbicides' are discussed in this chapter.

5.1. Part I: Survey and morphological study of different species and types of *Echinochloa* in rice fields of Palakkad rice tract

The serious problem of *Echinochloa* in Palakkad rice tract is aggravated by the appearance of a number of morphotypes or biotypes. Biotypes are plants showing a random genetic variant within an ecotype (Klingman and Oliver, 1994). Plant morphology under uniform conditions can be influenced by environmental conditions and plant genotype. It is reported that the morphological characters of *E. crus-galli* are affected by soil type and fertility level (Martines *et al.*, 1999). Most species of *Echinochloa* are highly polymorphic and variable in the characteristics usually considered, and are difficult to distinguish (Michael, 1983).

From the survey conducted in the major rice producing tracts of Palakkad district, three major *Echinochloa* types severely infesting rice fields and leading to crop-weed competition were identified. The three types included *E. colona* and two types of *E. crus-galli*, one with short awns designated as *Echinochloa crus-galli* (type A) and the other with longer awns named *E. crus-galli* (type B). The nomenclature *E. colona* was adopted in favour of *E. colonum* as per conclusion reached by Michael (2009).The frequency of distribution of *E. crus-galli* types were higher than that of *E. colona* in Palakkad rice tracts (Fig. 5). The two types of *Echinochloa crus-galli* were distinctly different with respect to awn length and arrangement of awns on the spikelets (Plate 10). In fact, the type collected and named as *Echinochloa crus-galli* (type A) had earlier been identified as *E. glabrescens* (Thomas and Abraham, 1998; 2007). In *E. crus-galli* (type A), the spikelets were broadly ovate to ovate with short awns up to 1.5 mm long. The awns were abundant and either scattered throughout the panicle or confined on the spikelets at the tip of the panicle branches. In *E. crus-galli* (type B), the spikelets were ovate with long awns distributed throughout the panicle. The length of awn went up to 11 mm. *E. colona*, on the other hand, was awnless. There were no other significant differences in the morphological characters recorded of *E. colona* and *E. crus-galli* types.

Semi-dry system of rice cultivation was followed throughout the survey locations in Palakkad rice tract, with saturated soil conditions. *Echinochloa* types were abundant in acidic to neutral pH prevailing in the area. Severe infestation of *Echinochloa* complex was observed in soils with high organic carbon, moderate nitrogen and phosphorus, and low to high potassium. There was no specific association between *Echinochloa* types and soil nutrient parameters, probably as there were no drastic differences in chemical properties between different locations. The rice fields of Palakkad district covered in the survey had similar soil properties leading to infestation by all the three types of *Echinochloa* throughout. *E. crus-galli* (type B) recorded a slightly higher relative frequency than *E. crus-galli* (type A), pointing to a better adaptability to the existing conditions.

Fig. 5. Relative frequency of *Echinochloa* species in Palakkad rice tract

***Echinochloa stagnina* in Kuttanad and Kole areas**

A major weed in Kuttanad in Alleppey and the Kole area in Thrissur was *E. stagnina,* also known by the synonym *E. picta* (Noltie, 2000). This species differed significantly from *E. colona* and the two types of *E. crus-galli*, and occurred only in flooded rice. It exhibited more tiller branching, but less number of branches and spikelets per panicle and less dry matter production. Long awns up to 9 mm length were characteristic of this species. Open panicles with few branches were another peculiarity (Plate 8).

Seed dormancy in species of *Echinochloa*

Effective weed management in a cropped field is often difficult due to the common occurrence of dormancy in weed seed populations, leading to unpredictable time extent of weed emergence. Dormancy is a commonly reported phenomenon in *Echinochloa*, especially in *E. crus-galli,* the seeds of which, even when fully hydrated, can persist in a dominant state (Di Nola *et al.*, 1991). In the present study, all the species of *Echinochloa* exhibited varying degrees of dormancy. Hot water treatment and sulphuric acid scarification were effective for breaking dormancy of *E. crus-galli* to some extent. Pre treatment with ethanol (1M) for three days under darkness was most effective for promoting germination of all types of *Echinochloa*. The presence of germination inhibitors in the seed coat of *E. colona* could be a possible cause of dormancy. Chun and Moody (1987) suggested that the inhibitor may be a phenolic compound.

Soaking in ethanol promoted the germination of dormant *Echinochloa* seeds. The removal of ethanol soluble compounds in the seed coat of *Echinochloa* could have resulted in higher germination percentage. Soaking seeds in ethanol has been reported to increase the concentration of O_2, which led to the oxidation of germination inhibitors, probably inducing a reaction mediated by peroxidase (Ogawa and Iwabuchi, 2001). Exposure to high temperature is reported to break dormancy and stimulate germination. Di Nola and Taylorson (1989) have reported that the composition of soluble and membrane bound protein in the cells was affected by a brief exposure of dormant *E. crus-galli* seeds to high temperature (46° C). This exposure stimulated subsequent germination at favourable temperatures.

However in the present experiment, seed germination was highest at a temperature of 25 – 30 °C, and the higher temperature (36 °C) reduced the germination percentage (Fig. 6).

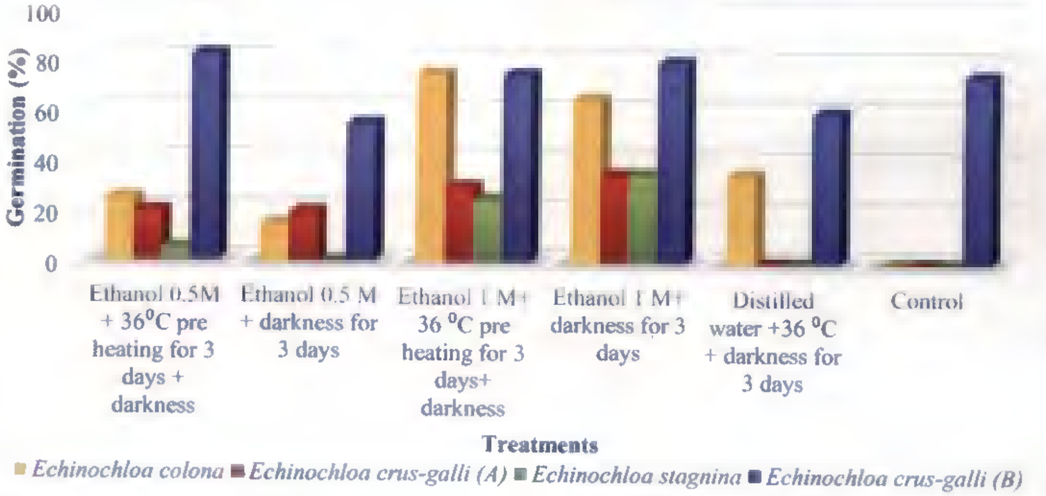


Fig 6. Effect of ethanol treatment on germination of *Echinochloa* spp.

5.2. Part II: Evaluation of efficacy of pre and post emergence herbicides on *Echinochloa* spp. by pot culture study

5.2.1. Efficacy of pre emergence herbicides

Pretilachlor 0.75 kg ha^{-1} was completely effective as a pre emergence herbicide in all the four types of *Echinochloa*. A study conducted by Opena *et al.* (2014) also suggested pretilachlor 0.075 kg ha^{-1} followed by flooding at a depth of 2 cm for controlling the emergence of *Echinochloa glabrescens.* Application of pretilachlor at a dose of 0.3 kg a.i. ha^{-1} alone also reduced the emergence of *Echinochloa glabrescens.* Pre emergence application of pretilachlor with a safener at 0.6 kg ha^{-1} controlled *E. crus-galli* and *E. colona* with 100 per cent weed control efficiency (Awan *et al.*, 2015).

Application of oxyfluorfen 23.5% EC at 0.15 kg ha^{-1} followed by hand weeding at 30 days after sowing resulted in a higher weed control efficiency of 90 per cent or more in wet-seeded rice (Abraham and Menon, 2015). In the present experiment also, oxyfluorfen at 0.15 kg ha^{-1} controlled the germination of all the four types of *Echinochloa* in wet seeded as well as dry seeded condition.

The efficacy of pyrazosulfuron-ethyl at 1.25 kg ha^{-1} was poor in *Echinochloa* types. It was more effective in drain-sown than in wet-sown condition. However, weed control efficiency up to 95.25 % in dry sown condition was recorded in *E. crus-galli* (type B). Gowda *et al.* (2009) recommended the application of pyrazosulfuron-ethyl at 0.03 kg ha^{-1} for controlling grass weeds. Kumar and Ladha (2011) also reported that *E. crus-galli* was effectively controlled by pyrazosulfuron-ethyl. The poor performance of pyrazosulfuron ethyl against other *Echinochloa* spp. in this study might be because it is most effective when applied early post emergence, i.e., 10 to 14 days after sowing (Juraimi *et al.*, 2013).

Pre application of pendimethalin at 1.5 kg ha^{-1} was completely effective in all the four types of *Echinochloa*. Awan *et al.* (2015) also reported that pre emergence application of pendimethalin at 1-2 kg ha^{-1} provided 100 per cent control of *E. colona* and *E. crus-galli.*

Pretilachlor + bensulfuron-methyl (0.6-0.06 kg ha^{-1}) at 10 kg ha^{-1} was 100 per cent effective for all the four types of *Echinochloa* in both wet seeded and dry seeded system. Sanjay *et al.* (2013) and Rao (2013) also reported that pretilachlor + bensulfuron-methyl (0.6-0.06) kg ha^{-1} was effective in both drain-seeded and wet-seeded systems.

Oxadiargyl at 0.1 kg ha^{-1} was 100 % efficient for all the four types of *Echinochloa*. A study conducted by Bhattacharya *et al.* (2005) substantiated these results, revealing that pre emergence application of oxadiargyl at 0.1 kg ha^{-1} showed excellent performance in reducing the population of *E. crus-galli*. Similarly, oxadiargyl at a dose of 0.075 kg ha^{-1} and more reduced the population of *E. crus-galli,* and greater efficiency against *E. crus-galli* was observed under anaerobic condition than aerobic condition (Gitsopoulos and Williams, 2003).

All pre emergence herbicides, with the exception of pyrasosulfuron ethyl, can be used in effectively controlling the different types of *Echinochloa.*

5.2.2. Efficacy of post emergence herbicides

Post emergence herbicides had varying effects on the different types of *Echinochloa*. Although herbicides which were known to be highly effective against the weed were evaluated, they were less effective in pot culture studies.

Echinochloa colona

Contrary to expectations, application of both cyhalofop butyl and fenoxaprop-p-ethyl at four leaf stage of *E. colona* was seen to be less effective, with more than 60 per cent seedling survival (Table 15). Fenoxaprop-p-ethyl performed better at eight leaf stage of the weed, suggesting that application at this stage would be more effective. Bispyribac sodium and metamifop were effective at both stages of the weed, indicating their superiority in controlling *E. colona*. Chauhan and Abugho (2012) have reported that post emergence application of bispyribac sodium at four leaf stage reduced the biomass of *E. colona* up to 95 per cent. Walia *et al.* (2008) reported that bispyribac sodium could bring about great reduction in the biomass accumulation of *E. colona* when applied at 30 DAS at a dose of 0.4 kg ha^{-1}. Weed persistence indices (Table 19) revealed that while seedling survival was high when cyhalopfop butyl was applied at four leaf stage, the dry matter production of the surviving seedlings was less, indicating disruption of the metabolic pathways. This is clearly seen in Fig. 7. A similar result was obtained with the application of fenoxaprop-p-ethyl at the eight leaf stage (Fig.14). The effectiveness of bispyribac sodium, metamifop and penoxsulam when applied at the four leaf stage are also brought out when survival percentage and WPI were compared (Figs. 9, 11 & and 17). Ethoxysulfuron was seen to be least effective among the herbicides applied.

***Echinochloa crus-galli* (type A)**

Application of bispyribac sodium at the eight leaf stage was highly effective against *E. crus-galli* (type A.). Bispyribac sodium has also been reported to be effective in rice nursery as well as main field against *E. crusgalli and E. glabrescens* (Duray and Mukherjee, 2013.) At the four leaf stage, although the survival was less, the persistence was comparatively higher (Tables 16 & 20). Survival percentage of the weed was less when fenoxaprop-p-ethyl, ethoxysulfuron, metamifop and penoxsulam were applied at the four leaf stage (Table 16). Prameela *et al.* (2014) obtained similar results. Cyhalofop butyl killed almost 80% of the weed seedlings. Similar results were reported by Ntanos *et al.* (2009) who observed that early post-emergence application of cyhalofop butyl at a rate of 0.15 – 2 kg ha^{-1} effectively controlled *E. crus-galli.* Jacob *et al.* (2014) also reported that cyhalofop butyl at the rate of 0.08 kg ha^{-1} was very effective against grass weeds when sprayed at 20 DAS. However at this stage the WPI was high (Table 20), indicating their inadequacy to completely control this particular species of *Echinochloa.* At eight leaf stage, these herbicides performed still more poorly (Figs.7 & 8), resulting in high dry matter production by the surviving seedlings (Fig. 8). At the eight leaf stage, both survival and persistence were higher when cyhalofop butyl was applied. So though an earlier application produced better results, the effect was seen to be 94 inadequate, pointing to a probable need for either a higher dose of application or a still earlier application. Sharma *et al.* (2004) recommended a dose of 0.09 kg ha^{-1} as optimum for controlling *Echinochloa* in the nursery. It follows that a higher dose is required for killing *Echinochloa* of advanced age. The time of application also has to be precise as a slight variation in age of the weed seedlings can render a herbicide ineffective. Ntanos *et al.* (2000) observed that weed control with cyhalofop butyl (200 g ha^{-1}) was reduced when applied at four leaf stage compared to the two leaf stage.

Echinochloa crus-galli (type B)

E. crus-galli (type B) was seen to be totally killed off by the application of metamifop at the four leaf stage, or penoxsulam at the eight leaf stage (Tables 17 & 21). However, Ottis *et al.* (2003) have reported that penoxsulam provided 99 per cent control of *Echinochloa crus-galli* at 21 DAT. Contrary to its effect on *E. colona* and *E. crus-galli* (type A), bispyribac sodium was seen to be ineffective against *E. crus-galli* (type B) at both stages of application (Tables 17 & 21). As shown in Figs.9 and 10, earlier application was ineffective in killing majority of the seedlings, while at the later stage, the persistence of the surviving seedlings was high. Fenoxaprop-p-ethyl was a good herbicide for *E. crus-galli* (type B) at the four leaf stage (Table 17). Similar results have been reported by Singh *et al.* (2004). Chauhan and Abugho (2011) have also observed poor control of *E. crus-galli* when fenoxaprop + ethoxy sulfuron (150 + 18 g ha^{-1}) was sprayed at the eight leaf stage, whereas at the four leaf stage the weed control efficiency was 68 per cent. In the present experiment, at the eight leaf stage, the surviving seedlings showed high persistence (Fig. 14).

The results revealed that although *E. crus-galli* (type A) and *E. crus-galli* (type B) were both morphologically similar (except in the length of awn) and identified to be the same (i.e., *E. crus-galli*), because of the varying effects of herbicides on these two types, they may be dissimilar genetically, and further studies in this line are necessary. In wheat, Rebetzke *et al.* (2016) found that awns 95 are coupled with larger grain size and yield in less favourable environments, but reduce grain number in more favourable environments. They also showed that awns do not significantly affect the total number of spikelets and anthesis time, but markedly increase the number of sterile spikelets and grain size in some environments. They also hypothesized that allocation of assimilates to large and rapidly developing awns decreases fertile spikelet number and floret fertility, and reduces grain number particularly in distal florets. So the increase in awn number and length in *E. crus-galli* (type B) must be having an evolutionary significance in the survival of plants under less favorable environments.

Echinochloa stagnina

E. stagnina, present in Kuttanad and the Kole lands, was significantly different from the other species of *Echinochloa* studied in its response to herbicides. Bispyribac sodium was found to be less effective against this species both at the four leaf and eight leaf stages (Tables 18 and 22). The surviving seedlings were highly persistent (Figs. 9 & 10). Cyhalofop butyl and fenoxaprop-p-ethyl, were both effective at the four leaf stage in reducing the survival percentage, but resulted in highly persistent survivors (Tables 18 & 22; Figs. 7 & 13). These herbicides were less effective at the eight leaf stage also. Metamifop, penoxsulam and ethoxysulfuron were seen to be ineffective at both stages.

It is a known fact that to be effective, the dose and time of application of herbicides are most important. Water management also plays an important role for ensuring herbicide efficacy (Haefele *et al.*, 2000). Increased age of weed seedlings may also reduce weed growth and increase weed biomass (Chauhan and Abugho, 2011). The development of tolerance to herbicides is also a factor to be considered. Development of adaptation strategies in weeds to escape control measures and to permit recovery have been speculated on. Azmi (2000) has observed that certain weed species may establish when a particular herbicide is continuously used either due to inherent properties or due to application of sub-lethal concentrations, leading to resistance. Changes in anatomical characteristics or in biochemical or physiological properties can help in making weeds best adapted to applied herbicides. This can lead to changes in the weed spectrum and in composition and distribution. Continuous monitoring and continuous modification in the management strategies adopted are required for dealing with the ever changing weed population.

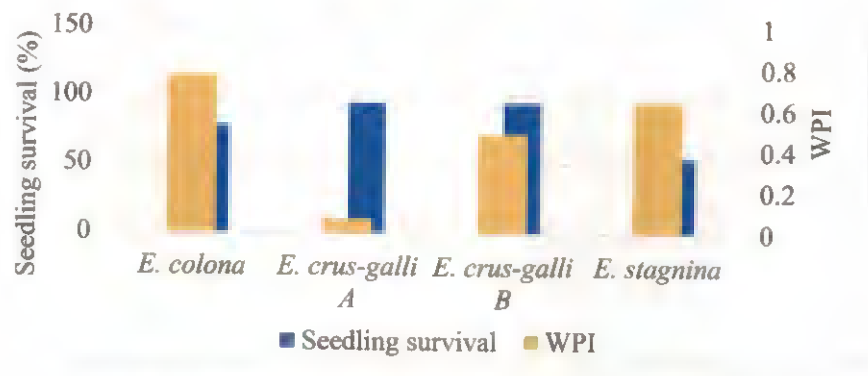


Fig. 7. Effect of cyhalofop butyl at four leaf stage

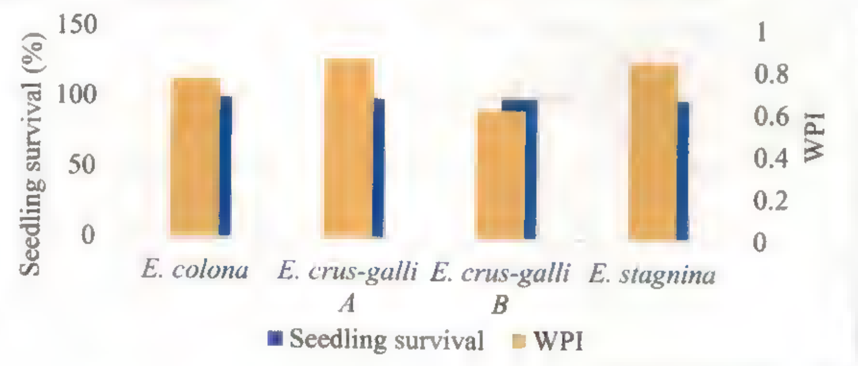


Fig. 8. Effect of cyhalofop butyl at eight leaf stage

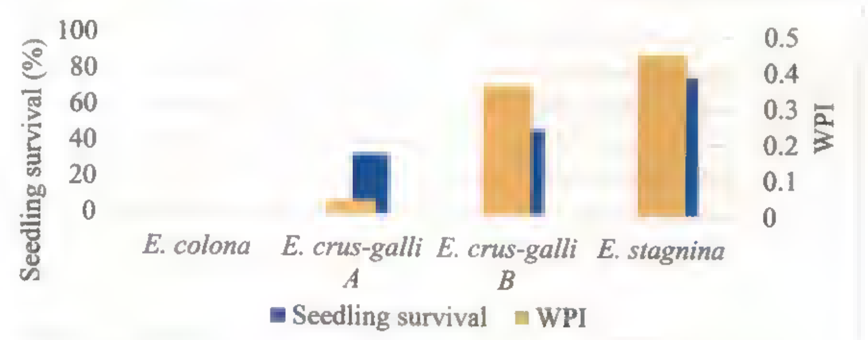


Fig. 9. Effect of bispyribac sodium at four leaf stage

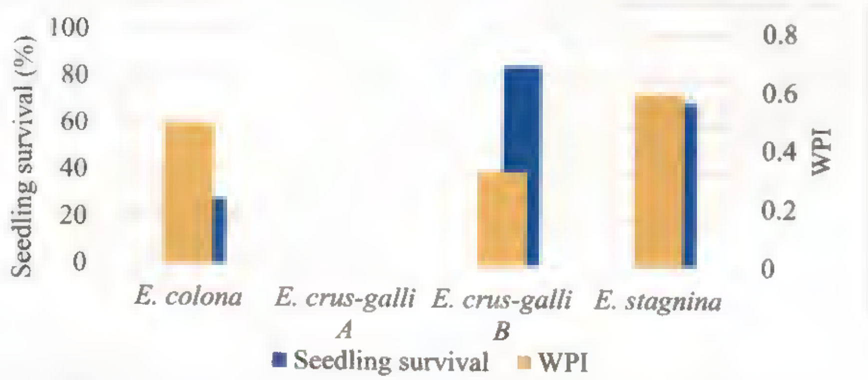


Fig. 10. Effect of bispyribac sodium at eight leaf stage

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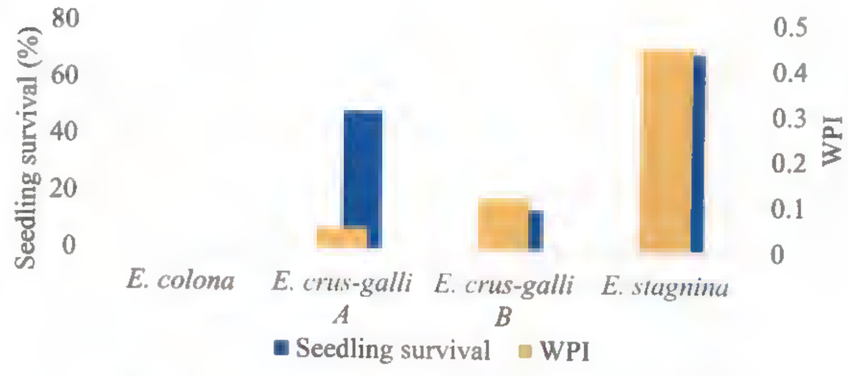

Fig. 11. Effect of penoxsulam at four leaf stage

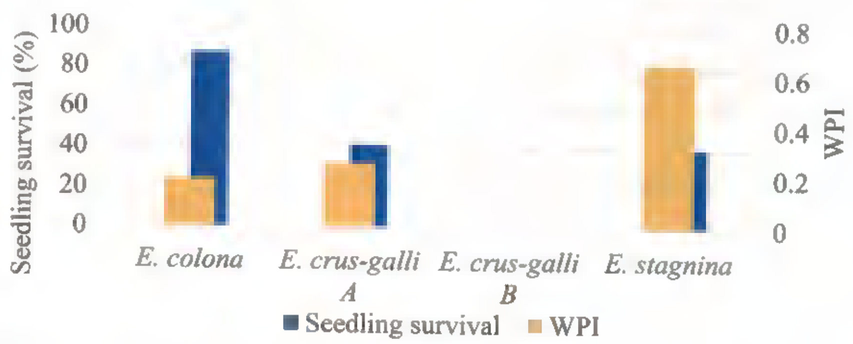

Fig. 12. Effect of penoxsulam at eight leaf stage

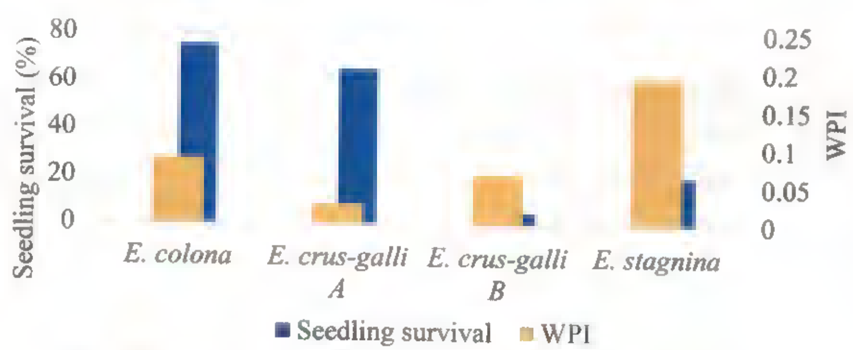

Fig. 13. Effect of fenoxaprop-p-ethyl at four leaf stage

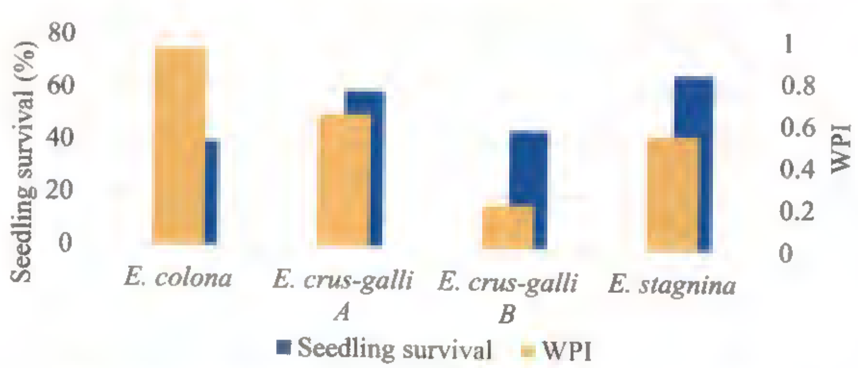

Fig. 14. Effect of fenoxaprop-p-ethyl at eight leaf stage

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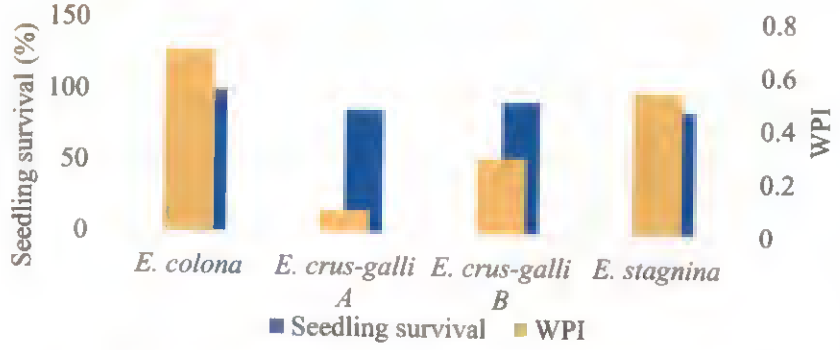

Fig. 15. Effect of ethoxysulfuron at four leaf stage

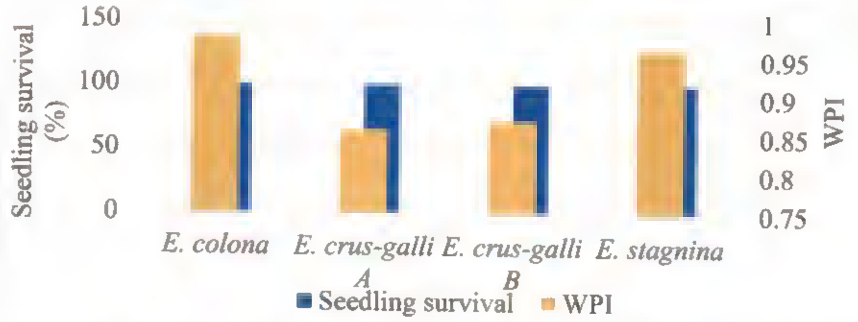

Fig. 16. Effect of ethoxysulfuron at eight leaf stage

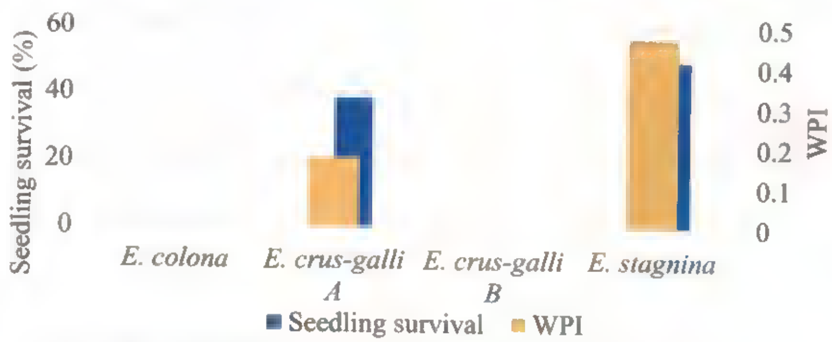

Fig. 17. Effect of metamifop at four leaf stage

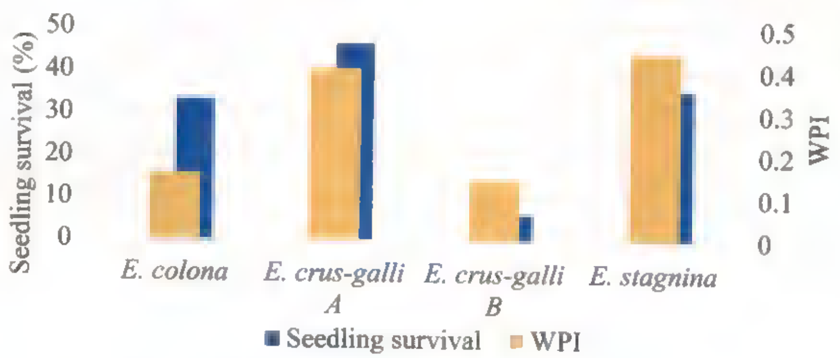

Fig. 18. Effect of metamifop at eight leaf stage

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Summary

6. SUMMARY

A study was conducted in 2016-17 at the College of Horticulture to study the diversity of *Echinochloa* spp. in the rice tracts of Palakkad and to test the efficacy of select pre and post emergence herbicides against them. The efficacy of herbicides was evaluated for the major *Echinochloa* species collected from Kuttanad and Kole lands too.

Three major *Echinochloa* types were identified infesting rice fields of Palakkad rice tract, leading to severe crop competition. The three types were *E. colona*, with awnless spikelets and two types of *E. crus-galli* viz., *E. crus-galli* (type A) having short awns and *E. crus-galli* (type B) having long awns. Other than the length and arrangement of awns, there were no other significant differences in the morphological characters of the two types of *E. crus-galli*.

Among the types of *Echinochloa*, the frequency of distribution in Palakkad and relative frequency were higher for *E. crus-galli* (type B) followed by *E. crus-galli* (type A) and *E. colona*.

E. stagnina was the dominant type of Kuttanadu and Kole lands and was found only in flooded soils. This species differed morphologically from the other three types collected from Palakkad rice tracts.

There was no specific association between the *Echinochloa* types in Palakkad rice tract and soil nutrient parameters, probably as there were no drastic differences in the chemical properties among the different locations. Saturated soil moisture regime was observed in all the rice fields of surveyed areas.

All the species of *Echinochloa* except *E. crus-galli* (type B) exhibited dormancy in varying degrees. Ethanol treatment was found to be most effective in enhancing germination rate of *Echinochloa* spp. Pre soaking of seeds of all the four types for three days in 1M ethanol under darkness was the best treatment; 80 per cent germination was recorded in *E. crus-galli* (type B) and 65 per cent in *E. colona* while the other two types recorded a germination of 35 per cent each. This treatment was therefore applied in the subsequent pot culture experiments.

In the pot culture study, pre emergence herbicides were treated under both puddle sown and dry sown conditions. Efficacy of post emergence herbicides were tested at four and eight leaf stages of *Echinochloa* under puddle sown conditions.

The pre emergence herbicide treatments included pretilachlor, oxyfluorfen, pyrazosulfuron ethyl, pendimethalin, pretilachlor + bensulfuron methyl and oxadiargyl, and all were applied to both puddle sown and dry sown condition. All the herbicides except pyrazosulfuron ethyl were completely effective against all the four types of *Echinochloa*. Plants grown in dry-sown condition were more susceptible to pyrazosulfuron-ethyl than those in puddle sown condition, registering less germination and emergence of *E. stagnina*. The susceptibility to pyrazosulfuron-ethyl was in the order *E. stagnina* > *E. crus-galli* (type A) > *E. colona* > *E. crus-galli* (type B).

Post emergence treatments included cyhalofop butyl, bispyribac sodium, penoxsulam, fenoxaprop-p-ethyl, ethoxysulfuron and metamifop.

Bispyribac sodium and metamifop were effective against *E. colona* at both four leaf and eight leaf stages, whereas penoxsulam was effective only at the four leaf stage. Bispyribac sodium at the eight leaf stage was highly effective against *E. crus-galli* (type A). *Echinochloa crus-galli* (type B) was effectively controlled by metamifop when sprayed at the four leaf and eight leaf stages, fenoxaprop-p-ethyl at the four leaf stage and penoxsulam at the eight leaf stage. Thus, the two types of *E. crus-galli,* although morphologically similar except in awn characters, had varying response to herbicides.

E. stagnina was tolerant to all the herbicides tried. However, cyhalofop butyl and fenoxaprop-p-ethyl although effective at the four leaf stage in reducing the survival percentage, resulted in highly persistent survivors.

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Appendix

Appendix 1: Plant identification certificate from Botanical Survey of India

भारत सरकार
GOVERNMENT OF INDIA
पर्यावरण, वन और जलवायु परिवर्तन मंत्रालय
MINISTRY OF ENVIRONMENT, FOREST & CLIMATE CHANGE
भारतीय वनस्पति सर्वेक्षण
BOTANICAL SURVEY OF INDIA

दक्षिणी क्षेत्रीय केन्द्र / Southern Regional Centre
टी.एन.ए.यू कैम्पस / T.N.A.U. Campus
लाउली रोड / Lawley Road
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ई-मैल /E-mail id: sc@bsi.gov.in
bsisc@rediffmail.com

सं. भा.व.स./द.क्षे.के./No.: BSI/SRC/5/23/2017/Tech./3664 दिनांक/Date: 31st March 2017

सेवा में / To

Ms. Aparna K.K.
M. Sc. (Ag.) Student
Department of Agronomy
College of Horticulture
K.A.U. P.O., Thrissur
Kerala – 680 656

महोदया/Madam,

The plant specimens given by you for authentication are identified as follows:

Plant sample (1) *Echinochloa crusgalli* (L.) P. Beauv. – POACEAE
Synonym: *Panicum crusgalli* L.
Echinochloa glabrescens Munro ex Eggel.
Echinochloa oryzoides auct non (Ard.) Fritsch

Plant Sample (2) *Echinochloa picta* (J. Koenig) P.W. Michael - POACEAE
Synonym: *Panicum pictum* J. Koenig
Echinochloa stagnina (Retz.) P. Beauv.

Plant Sample (3) *Echinochloa crusgalli* (L.) P. Beauv. POACEAE
Synonym: *Panicum crusgalli* L.

Plant Sample (4) *Echinochloa colonum* (L.) Link - POACEAE
Synonym: *Panicum colonum* L.

Plant Sample (5) *Echinochloa crusgalli* (L.) P. Beauv. POACEAE
Synonym: *Panicum crusgalli* L.

Plant Sample (6) *Echinochloa colonum* (L.) Link POACEAE
Synonym: *Panicum colonum* L.

The identified specimens are returned herewith for preservation in their College/ Department/ Institution Herbarium. The receipt bearing No. 1031 dated 31.03.2017 for ₹300/- towards the fee for identification is enclosed herewith.

धन्यवाद/Thanking you,

भवदीय/Yours faithfully,

31/03/2017

(डॉ सी मुरुगन/Dr. C. Murugan)
वैज्ञानिक 'डी' एवं कार्यालय अध्यक्ष /
Scientist 'D' & Head of Office

31/3/2017

DIVERSITY OF *Echinochloa* spp. AND THEIR RESPONSE TO SELECT HERBICIDES

By

APARNA K. K.

(2015-11-051)

ABSTRACT OF THE THESIS

Submitted in partial fulfillment of the requirements for the degree of

Master of Science in Agriculture

Faculty of Agriculture

Kerala Agricultural University

DEPARTMENT OF AGRONOMY

COLLEGE OF HORTICULTURE

VELLANIKKARA, THRISSUR – 680656

KERALA, INDIA

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ABSTRACT

The most important biological constraint to rice production is weed infestation. *Echinochloa* spp. are the most devastating and serious graminaceous weeds associated with rice. Herbicides which selectively kill *Echinochloa* are commonly used by rice farmers, as hand weeding is often ineffective due to its close morphological similarity to rice. Of late, some new types of *Echinochloa* are seen in the major rice tracts of Kerala, and farmers report that these new types are tolerant to most herbicides used by them. The present study was conducted to study the diversity of *Echinochloa* spp. in the rice tracts of Palakkad and to test the efficacy of select herbicides against them. The efficacy of herbicides was evaluated for the major *Echinochloa* species collected from Kuttanad and Kole lands too.

Surveys were conducted twice in the major rice tracts of Palakkad, once during January-February, and the other during August-September in 2016. Three major *Echinochloa* types were identified infesting rice fields, leading to severe crop competition. The three types were *E. colona*, with awnless spikelets and two types of *E. crus-galli* viz., *E. crus-galli* (type A) having short awns and *E. crus-galli* (type B) having long awns. Other than the length and arrangement of awns, there were no other significant differences in the morphological characters of the latter two types.

There was no specific association between the *Echinochloa* types and soil nutrient parameters, probably as there were no drastic differences in the chemical properties among the different locations. Saturated soil moisture regime was observed in all the rice fields of surveyed areas.

The major species in Kuttanadu and Kole area was *E. stagnina,* which was found only in flooded soils. This species differed morphologically from the other three types collected from Palakkad rice tracts.

All the types, except *Echinochloa crus-galli* (type B) exhibited seed dormancy. Pre-treatment with ethanol (1M) for three days under darkness was most effective for promoting germination of *Echinochloa*.

The efficacy of pre and post emergence herbicides on various species of *Echinochloa* was evaluated as pot culture study. The pre emergence herbicide treatments included pretilachlor, oxyfluorfen, pyrazosulfuron ethyl, pendimethalin, pretilachlor + bensulfuron methyl and oxadiargyl, and all were applied to both puddle sown and dry sown condition. All the herbicides except pyrazosulfuron ethyl were completely effective against all the four types of *Echinochloa*.

Post emergence treatments were applied at the four leaf and eight leaf stages of *Echinochloa* spp. and the treatments included cyhalofop butyl, bispyribac sodium, penoxsulam, fenoxaprop-p-ethyl, ethoxy sulfuron and metamifop.

Bispyribac sodium and metamifop were effective against *E. colona* at both four leaf and eight leaf stages, whereas penoxsulam was effective only at the four leaf stage. Bispyribac sodium at the eight leaf stage was highly effective against *E. crus-galli* (type A). *Echinochloa crus-galli* (type B) was effectively controlled by metamifop when sprayed at the four leaf and eight leaf stages, fenoxaprop-p-ethyl at the four leaf stage and penoxsulam at the eight leaf stage. This indicated that though the two types of *E. crus-galli* were morphologically similar except in awn characters, they had varying response to herbicides. *E. stagnina* was tolerant to all the herbicides tried. However, cyhalofop butyl and fenoxaprop-p-ethyl although effective at the four leaf stage in reducing the survival percentage, resulted in highly persistent survivors.

The study showed the importance of optimal use of the correct herbicide against each species of *Echinochloa* at the most susceptible stage of the weed. Constant monitoring of the *Echinochloa* population in the field is important so that appropriate control strategy can be adopted.