Taiwania 64(3): 221-230, 2019
DOI: 10.6165/tai.2019.64.221

Seed dormancy and germination of seven rice field weeds from Sri Lanka

H. G. Sashika SUMUDUNIE[1,*], K. M. G. Gehan JAYASURIYA[1,2]

1. Department of Botany, University of Peradeniya, Peradeniya, Sri Lanka.
2. Postgraduate Institute of Science, University of Peradeniya, Peradeniya, Sri Lanka.
[*]Corresponding author's email: hgssumudunie@gmail.com

(Manuscript received 4 January 2019; accepted 26 May 2019; online published 19 June 2019)

ABSTRACT: Weeds associated with rice fields cause severe yield reduction and many other problems. Effective weed management strategy depends on knowledge of weed seed biology. This study aimed to determine basic seed biology information of seven rice field weeds in Sri Lanka. Seeds were collected from at least five individuals from each species. Dormancy classes of seeds were determined using germination and imbibition experiments. Effect of light, dry storage, temperature and salinity on dormancy and germination was studied. Experiments were conducted with three replicates of 25 seeds. Among the tested species, seeds of *Eclipta prostrata* and *Ludwigia peruviana* were non-dormant where the non-treated fresh seeds germinated > 60 %. Seeds of *Aeschynomene indica* and *Melochia corchorifolia* are physically dormant as only scarified seeds imbibed and germinated. *Fimbristylis miliacea, Cyperus pilosus* and *L. decurrens* seeds germinated only on GA_3. Thus, they have physiological dormancy. *E. prostrata* and *L. peruviana* seeds required light for germination. Five month- dry storage reduced the viability of *E. prostrata* seeds. In contrast, dry storage increased the sensitivity to the dormancy breaking treatment of *A. indica, M. corchorifolia, C. pilosus* and *L. decurrens* seeds and decreased the sensitivity of *F. miliacea* seeds. Germination of *E. prostrata* and *L. peruviana* seeds decreased with decreasing osmotic potential. Although, dormancy and dormancy breaking requirements vary among study species, keeping the rice field dry during the intercropping period could induce the seed germination of most of the above species and could be used as a mechanism to reduce the soil seed bank.

KEY WORDS: Germination requirements, No-dormancy, Physical dormancy, Physiological dormancy, Weed biology.

INTRODUCTION

Seed dormancy, germination requirements and longevity are important traits that determine the terminus of plants. Especially, these traits are the key features of weed seeds that promote their success (Kon *et al*., 2007). Therefore, studies on weed seed biology are important in designing more effective weed management strategies. However, the information on seed biology is scant on weedy species in Sri Lanka.

Weeds in cultivated rice fields reduce crop yield and quality of the yield by competing for growth requirements of the rice plants; nutrients, water, light and space (Hakim *et al*., 2011a). According to Chandrasena (1997), weeds are the main cause for intensification of diseases, insect and other pest problems by serving as alternative hosts. The aquatic weeds reduce the flow of water leading to problems in irrigation systems. Further aquatic weeds deplete the habitat for aquaculture and cause rapid water loss through evaporation (Rajapakse *et al*., 2012). Weed seed contamination of rice grains lowers the grain quality and may lower the cash value of the crop (Odero and Rainbolt, 2011). Further, weeds reduce the productivity of lands and thus reduce the property value. Thus, weed control has become an essential task in croplands. Currently, the most preferable, easy, quick and direct weed control method is the usage of herbicides. However, frequent usage of herbicides has induced herbicide resistance in many weeds (Sangakkara *et al*., 2004). Further, herbicides cause several adverse environmental effects. Thus, a more efficient, environmentally friendly, low-cost weed control methods should be introduced to the agriculture system of Sri Lanka. Integrated Weed Management (IWM) is a special kind of approach, where several weed control methods applied in an environmentally harmless way (Chandrasena, 1997). As there are many weed control methods integrated into IWM, weeds are not capable of developing resistance to all these methods. Further, weed control methods in IWM are applied in a controlled manner with continuous monitoring, which make IWMS less harmful than the popular chemical weed control systems. However, to develop an efficient IWM system, it is necessary to understand the biology of the weeds, especially the propagation biology of weeds should be thoroughly understood (Rajapakse *et al*., 2012).

Weed seed dormancy and germination are regulated by a complex interaction of environmental, physiological and genetic factors (Dyer, 1995). Temperature, light, salinity and water potential were identified as some of the environmental factors that can influence the weed seed dormancy and germination. Among them, the temperature has been identified as the main factor governing the changes in the degree of dormancy (Benech- Arnold *et al*., 2000). Exposure to light also triggers the germination in seeds of many weedy species (Dyer, 1995). There are reports that the specific needs for germination of weed seeds resemble

Table1. Information about distribution and seed collection of each study species

Species	Distribution in Sri Lanka	Seed collected site and month	Special remarks
Aeschynomene indica	Throughout the island (Rudd, 1991)	Peradeniya January, 2014	Important medicinal plant in Ayurvedic medicine (Aruna *et al*. 2012)
Cyperus pilosus	Low country wet zone (Harriman, 1994)	Peradeniya January, 2014	Infests forming very conspicuous heavy infestations (Chandrasena, 1997)
Fimbristylis miliacea	Low country wet zone (Harriman, 1994)	Peradeniya January, 2014	Allelopathic effects on the growth of rice plants (Ismail and Siddique, 2012)
Eclipta prostrate	Low country wet zone (Grierson, 1980)	Peradeniya January, 2014	Contain antibacterial (Khan and Khan, 2008) and anthelmintic (Bhinge et al., 2010) chemicals.
Ludwigia decurrens	Throughout the wet zone (Chandrasena, 1997)	Galle February 2014	High competitive ability due to high growth rate and extensive spongy root system (Dharmaratne and Ranamukaarachchi, 1991).
Ludwigia peruviana	Low country wet zone (Chandrasena, 1997	Galle February 2014	Dominant vegetation and in wetland rice fields mainly on bunds (Chandrasena, 1997).
Melochia corchorifolia	Low country wet zone (Chandrasena, 1988)	Kurunegala February 2014	Leaves used as vegetable (Ajaib and Khan, 2010). Medicoinal plant in traditional medicine (Pullaiah, 2014; Rao *et al*., 2013)

those of the cultivated plants (Steinbaeur and Grigsby, 1957). Our study aimed to gather the basic information on seed biology of some of the selected rice field weeds in Sri Lanka. Specifically, seed dormancy classes of these weeds were categorized and natural dormancy breaking mechanisms, effects of light, temperature and osmotic potential on germination were determined. In this research we selected seven common rice field weeds belong to five different families hypothesizing that the dormancy, dormancy breaking and germination requirements of these seven species are similar to each other as they are adapted to synchronize with rice cultivation.

MATERIALS AND METHODS

Study Species

Seven common rice field weeds of Sri Lanka; *Aeschynomene indica* (Fabaceae), *Cyperus pilosus* (Cyperaceae), *Fimbristylis miliacea* (Cyperaceae), *Eclipta prostrata* (Asteraceae), *Ludwigia decurrens* (Onagraceae), *Ludwigia peruviana* (Onagraceae) and *Melochia corchorifolia* (Malvaceae) were studied in the current research. The distribution information of the studied species is shown in table 1.

Seed collection

Mature fruits of study species were collected from numerous haphazardly selected plants in rice fields located in different locations in wet and intermediate zones in Sri Lanka as depicted in table 1. Collected fruits were kept in polythene bags, brought to the Department of Botany, University of Peradeniya, Sri Lanka. The seeds were extracted from the fruits and stored dry in closed glass vials under ambient laboratory conditions until used for experimentation at least within 2 weeks from the date of collection.

Determination of the class of seed dormancy

Germination test

This experiment was conducted to determine whether seeds are dormant or not. Three samples from each species containing three replicates with 25 untreated seeds were placed on moistened filter papers in Petri dishes and incubated at 15, 25 and 35 °C in light/dark (14 /10 hr photoperiod, cool white fluorescent light with the intensity ~ 40 μmol $m^{-2}s^{-1}$) conditions. Samples were checked for germination at 2-day intervals for 30 days. Radical emergence (about 0.5 mm) was the criterion for germination. The same experiment was conducted for manually scarified seeds of *A. indica* and *M. corchorifolia* at 25 °C in light/dark conditions.

Imbibition test

The purpose of this experiment was to determine whether seeds have physical dormancy (PY) or not. If intact seeds fail to increase in seed mass during imbibition, while manually scarified seeds imbibe and increase in mass confirm seeds have PY. However, the imbibition test was conducted only for seeds of *A. indica* and *M. corchorifolia*, because these two species belong to families reported with water impermeable seed coats i.e., seeds with PY (Baskin and Baskin, 2014). Two seed samples containing 12 untreated (intact) or manually scarified (individually with scalpel) seeds each were individually weighed to the nearest 0.0001 g using a digital chemical balance. They were placed on moistened filter papers in two 50 mm-diameter Petri dishes, separately at ambient laboratory temperature (~28 °C). Seeds were retrieved at two-hour intervals, surface blotted with filter paper, reweighed and returned to Petri dishes. The experiment was conducted for 6 hours until all the manually scarified seeds were fully imbibed.

Effect of Gibberellic acid (GA_3) on seed dormancy

The purpose of this experiment was to determine the level of dormancy in seeds with physiological dormancy (PD). A sample of three replicates containing 25 intact seeds each of *L. decurrens* or *C. pilosus* were incubated on filter papers moistened with 500 ppm GA_3 solutions, separately. The sample was kept at 25 °C in light/dark conditions. These seeds were checked for germination at 2-day intervals for 30 days.

Effect of complete darkness on seed germination and dormancy

This experiment was conducted to determine the light or dark requirement of seeds for germination. Light-insensitive seeds germinate well in both light/dark regime and in complete darkness. While light-sensitive seeds either germinate in light/dark regime or in complete darkness. Samples from all the tested species containing three replicates with 25 untreated seeds were placed on moistened filter papers in Petri dishes and incubated at 25 °C in complete darkness. Complete darkness was provided by wrapping Petri dishes with aluminium foil. Samples were checked for germination after 14 days and then at 2-day intervals for another 16 days. Radical emergence (~ 0.5 mm) was the criterion for germination. The experiment was conducted also for manually scarified *A. indica* or *M. corchorifolia* seeds.

Effect of dry storage on seed dormancy and viability

Dry conditions alleviate the physiological and physical dormancy of some species (Baskin and Baskin, 2014). Thus, the experiment was conducted to determine the effectiveness of dry conditions on breaking seed dormancy of study species. Three samples with three replicates containing untreated 25 seeds from each species separately were stored dry at ambient laboratory temperature conditions for 5 months. Retrieved seed samples were placed on moistened filter papers in Petri dishes and incubated at 15, 25 and 35 °C under light/dark conditions. Seeds were checked for germination at 2-day intervals for 30 days. Radicle emergence was the criterion for germination.

Effect of salinity and temperature on germination of nondormant seeds

As *L. peruviana, L. decurrens* and *E. prostrata* occur in the coastal zone to the mid-elevation rice fields (Chandrasena, 1997), seeds of these species could expose to different salinity conditions and thus the effect of salinity on germination of two out of above three species (*L. peruviana* and *E. prostrata*) were studied. Four samples of three replicates containing 25 seeds of *L. peruviana* or *E. prostrata* were incubated on filter papers moistened with NaCl solutions at 0, -0.5, -1.0 and -2.0 MPa osmotic potentials at 25 °C in light/dark conditions. Seeds were checked for germination in 2-day intervals. Radicle emergence was the criterion for germination. The same experiment was conducted at 15 and 35 °C.

Analysis of data

Imbibition data was analyzed using a pooled t-test. Results obtained from germination tests were analyzed using one-way and two- way ANOVA procedures. The data were arcsine transformed prior to analysis. All the data were analyzed using MINITAB statistical software.

RESULTS

Germination test

Germination percentages of fresh *E. prostrata* and *L. peruviana* seeds at 25 °C in light/dark conditions were 75 and 61.3 %, respectively. Seeds of both of these species also germinated at 15 and 35 °C to a significantly high percentage (Fig.1A). However, germination percentages of *E. prostrata* at 3 temperature regimes significantly differed from each other ($F = 22.6$, $P = 0.002$) while, germination percentage of *L. peruviana* seeds at different temperatures (Fig.1B) were not significantly different from each other ($F = 0.51$, $P = 0.622$). Germination percentages of *A. indica*, *M. corchorifolia*, *C. pilosus* and *F. miliacea* at 25 ˚C under light/dark conditions were < 50 % (Fig. 1). None of the *L. decurrens* seeds germinated at any of the three tested temperatures, while none of the *A. indica* or *M. corchorifolia* seeds germinated at 15 °C. Germination of *M. corchorifolia* seeds at different temperatures in light/dark condition differed significantly ($F=19.7$, $P=0.002$) (Fig.1D) while, germination of *C. pilosus* seeds at tested temperatures were not significantly different ($F = 0.70$, $P = 0.532$). Germination percentage of *F. miliacea* at 35 °C (49.7 %, Fig.1F) was significantly high compared to that at 15 or 25 °C ($F = 16.6$, $P = 0.004$). Manual scarification has significantly increased the germination percentage of seeds of both *A. indica* ($F = 68.4$, $P < 0.001$) and *M. corchorifolia* ($F = 161.8$, $P < 0.001$) and both species have shown > 80 % germination at 25 °C after manual scarification (Fig.2.A and B).

Imbibition test

The mass of manually scarified *A. indica* seeds increased > 80 %, while the mass of intact seeds increased only < 1 % (Fig.3A) within 6 hrs of imbibition at ambient laboratory temperature. Imbibition of manually scarified seeds and that of intact seeds differed significantly ($T = 26.82$, $P < 0.001$). The same trend was observed in *M. corchorifolia* seeds. All the manually scarified seeds of both species germinated within 24 hours at ambient laboratory temperature.

Effect of gibberellic acid (GA_3) on dormancy break

Seed germination of the two tested species has significantly influenced by the GA_3 treatment. Seed germination percentage of *L. decurrens* was significantly improved by incubating them on GA_3 (500 ppm) moistened filter papers at 25 °C (Fig. 4A, $F = 174.9$, $P = 0.001$). Similarly, *C. pilosus* seeds had significantly higher germination percentage on GA_3 compared to germination of seeds on distilled water (Fig. 4B, $F = 30.9$, $P = 0.005$).

Effect of complete darkness on seed germination

Germination percentage of untreated *A. indica* and *M.*

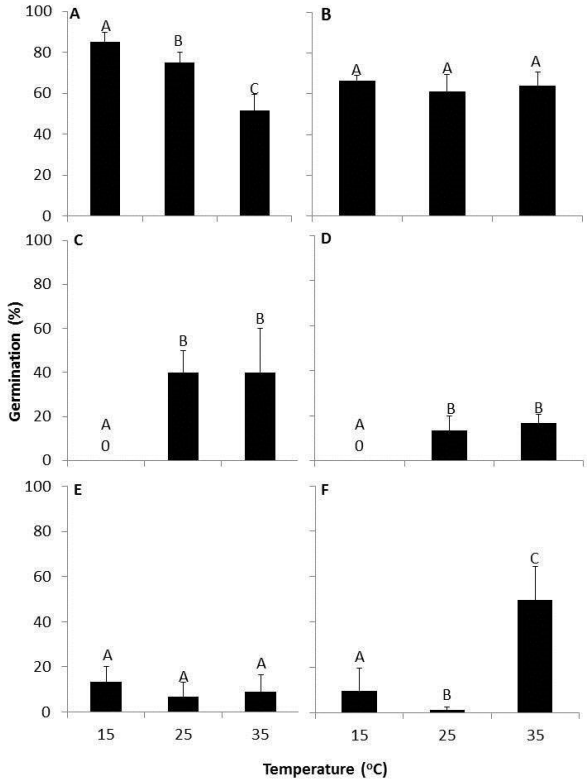

Fig. 1. Seed germination of ***Eclipta prostrata*** (**A**), ***Ludwigia peruviana*** (**B**), ***Aeschynomene indica*** (**C**), ***Melochia corchorifolia*** (**D**), ***Cyperus pilosus*** (**E**) and ***Fimbristylis miliacea*** (**F**) at different temperature regimes in light/dark conditions within 30 days. Different uppercase letter indicates significant differences between treatments. Error bars are + SD.

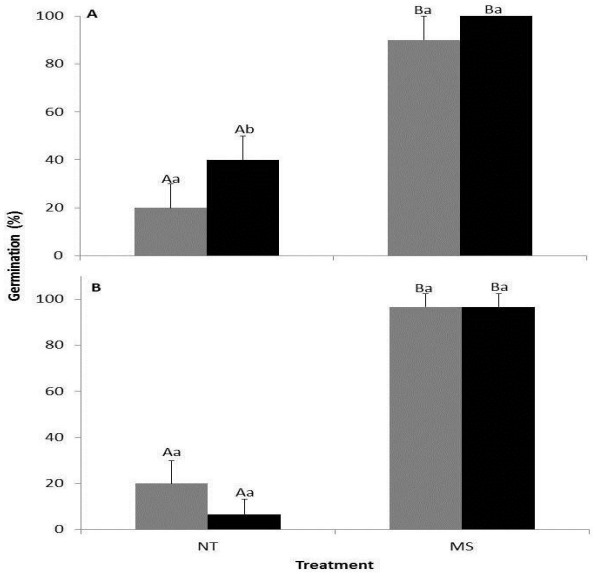

Fig. 2. Germination of non-treated (NT) and manually scarified (MS) seeds of ***Aeschynomene indica*** (**A**) and ***Melochia corchorifolia*** (**B**) under complete darkness (D) and light/dark (L/D) conditions at 25 °C within 30 days. Different uppercase letters indicate significant differences between treatments under the same light conditions. Different lowercase letters indicate significant differences between light conditions within the same treatment. Error bars are + SD.

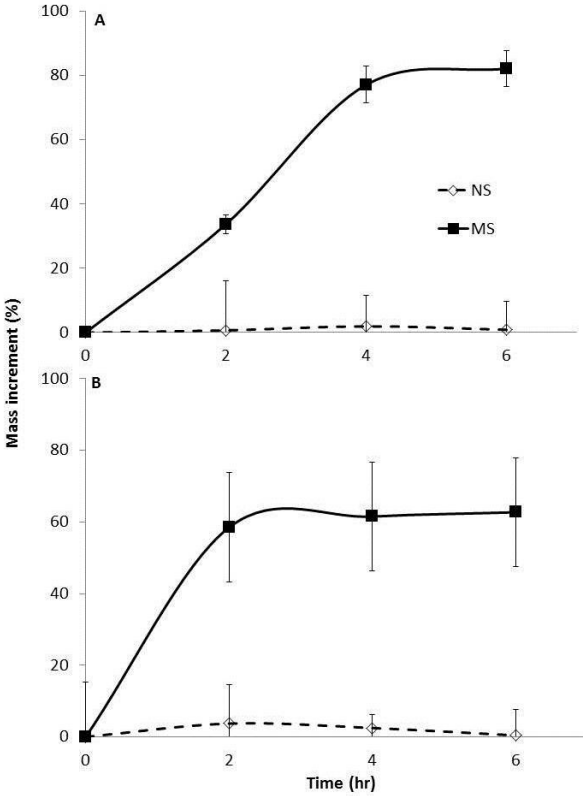

Fig. 3. Mass increment of manually scarified (MS) and intact (NT) seeds of ***Aeschynomene indica*** (**A**) and ***Melochia corchorifolia*** (**B**) at ambient laboratory temperature on distilled water moistened tissue papers in Petri dishes. Error bars are ± SD.

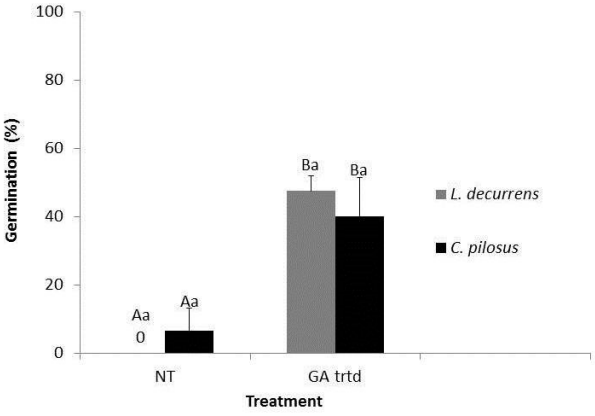

Fig. 4. Germination of GA_3 treated (GA trtd) and non-treated (NT) ***Ludwigia decurrens*** and ***Cyperus pilosus*** seeds incubated at 25 °C within 30 days. Different uppercase letters indicate significant differences between treatments within the same species. Different lowercase letters indicate significant differences between different species within the same treatment. Error bars are +SD.

corchorifolia seeds at 25 °C under dark conditions was ~20 %. None of the seeds of all the other species germinated in complete darkness (data not shown). However, manually scarified seeds of *A. indica* and *M. corchorifolia* germinated > 90 % within 2 days at 25 °C in complete darkness (Fig. 2). Germination of manually scarified seeds of these two species in light/dark condition is not significantly different from that in complete darkness (for *M. corchorifolia*, F ~ 0.00, P ~1.000 and for *A. indica* F = 1.00, P = 0.37).

Effect of dry storage on seed dormancy and viability

Dry storage of seeds of the study species reduced or increased the germination except in seeds of *L. peruviana* (F = 0.84, P = 0.37) (Fig. 5A). No significant difference was observed between the germination of dry stored seeds and that of untreated fresh *L. peruviana* seeds (Fig. 5A). None of the *E. prostrata* seeds germinated at 15, 25 or 35 ºC, after they were stored dry at ambient laboratory temperature for 5 months (data not shown). Further, they have rotted and died during the incubation. Dry storage also reduced the germination percentage of *F. miliacea* seeds at 15 and 35 °C, while at 25 °C dry stored *F. miliacea* seeds germinated to a higher percentage than the untreated seeds (Fig. 5E).

Germination percentage of seeds of all the other tested species have increased after 5 month-dry storage. Interaction effect of incubation temperature and dry storage period at room temperature on seed germination of *L. decurrens* is significant (F = 2428.89, P < 0.001). Germination of dry stored seeds of this species is > 75 % at 35 °C compared 0 % germination of non-treated fresh seeds. Five months dry stored intact *A. indica* seeds germinated to 83.3 % at 35 °C, where at other two temperatures the germination of stored seeds was significantly low (Fig. 5B). However, germination percentage of 5 months dry stored *A. indica* seeds incubated at 25 ºC was significantly higher than to that of untreated intact seeds (F = 8.6, P = 0.012). Five months dry stored *M. corchorifolia* seeds showed a similar trend to that of stored *A. indica* seeds (Fig. 5C). *Cyperus pilosus* has shown an increased percentage of germination (49.6 %) at 25 °C after they were stored dry at ambient laboratory conditions (Fig. 5F). Germination percentage at 15 and 25 °C was also slightly higher after the dry storage than that of untreated seeds. Interaction effect of incubation temperature and dry storage on seed germination (F = 11.3, P = 0.002) was significant.

Effect of salinity and temperature on seed germination

Seed germination of tested species, *E. prostrata* and *L. peruviana* was significantly influenced by the salinity of the germinating medium, at all the three tested temperatures (15, 25 and 35 °C). Germination percentage of both species reduced with reducing osmotic potentials. None of the seeds of both species germinated on -2.0 MPa at all the tested temperatures.

Germination percentage of *E. prostrata* seeds was highest at 15 °C for all the tested osmotic potentials and germination percentage was higher in distilled water (0 MPa) than in other NaCl mediated osmotic potentials at the three tested temperatures (Fig. 6A). Effect of temperature (F = 656.6, P < 0.001) and the effect of salinity (F= 1344.9, P < 0.001) on germination of *E. prostrata* seeds were significant. The highest germination percentage of *L. peruviana* seeds was also recorded on distilled water (0 MPa) at all the tested temperatures (Fig. 6B). Effect of temperature (F = 5.3, P = 0.013) and the effect of NaCl mediated osmotic potential (F = 60.2, P < 0.001) on germination of *L. peruviana* were significant.

DISCUSSION

Eclipta prostrata and *L. peruviana* seeds germinated > 60 % at all the tested temperatures within 30 days. Thus, it revealed that seeds of these two species are non-dormant. Highest germination of *E. prostrata* seeds was at 15 ºC showing that *E. prostrata* seeds have even adapted for low-temperature conditions. However, *L. peruviana* seed germination was not significantly influenced by the temperature.

Although the seeds of *E. prostrata* and *L. peruviana* were germinated to a significantly high percentage in light/dark conditions, none of their seeds germinated in complete darkness. Therefore, it can be concluded that the germination of these two species depends on light. Thus, these seeds can be categorized as positively photoblastic seeds. Further, we can conclude that *A. indica* and *M. corchorifolia* seeds do not require light for germination as manually scarified seeds of these two species germinated equally well in both light/dark and in complete darkness. Thus, they are light insensitive seeds. However, it is not possible to conclude on the light requirement of *L. decurrens*, *C. pilosus* and *F. miliacea* as germination of non-dormant seeds of these species was not tested under dark conditions. Our observations on *E. prostrata* are in accordance to the observations of Altom and Murray (1996) and Chauhan and Johnson (2008a) as they have reported that seed germination of *E. prostrata* is strongly influenced by light and the germination is completely inhibited at complete darkness. Further, Wilson and Swarbrick (1993) have reported that germination of *L. peruviana* seeds is inhibited by shade conditions. The light dependency of seeds has been reported for several *Ludwigia* species. As an example, Chauhan and Johnson (2009a) have reported that the germination of *Ludwigia hyssopifolia* is positively photoblastic.

Among the study species, *A. indica* (family: Fabaceae) and *M. corchorifolia* (family: Malvaceae) belong to

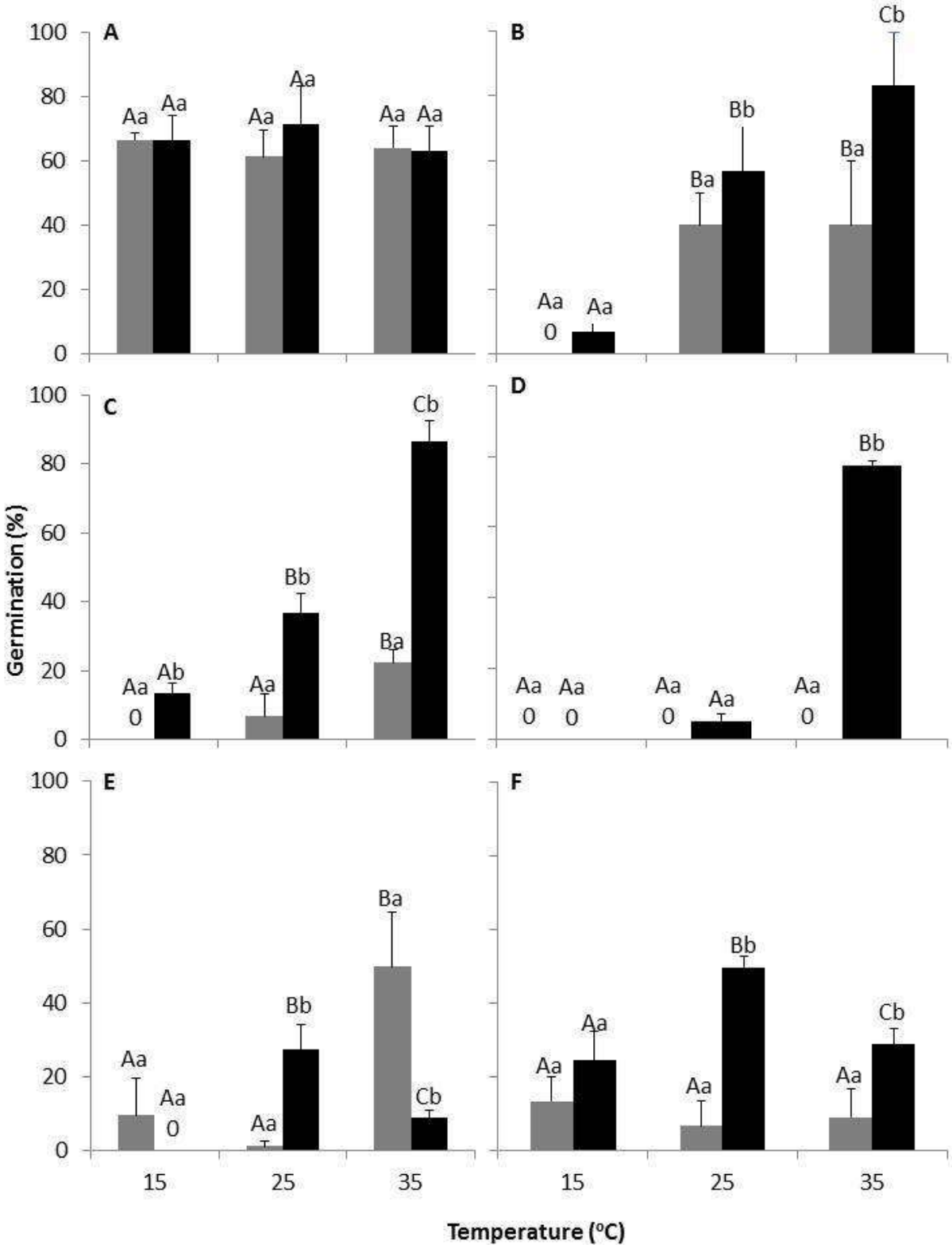

Fig. 5. Germination of 5 months dry stored (Dark bars) and non-treated fresh (Grey bars) seeds of ***Ludwigia peruviana*** (**A**), ***Aeschynomene indica*** (**B**), ***Melochia corchorifolia*** (**C**), ***Ludwigia decurrens*** (**D**), ***Fimbristylis miliacea*** (**E**), and ***Cyperus spilosus*** (**F**) at different temperature regimes in light/dark conditions. Different uppercase letters indicate significant differences between different incubation temperatures. Different lowercase letters indicate significant differences between storage treatments within the same incubation temperature. Error bars are + SD.

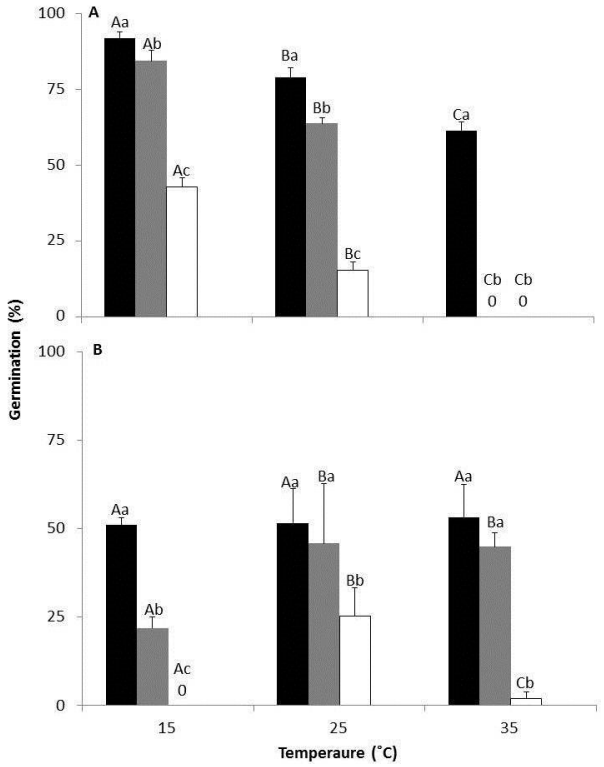

Fig. 6. Germination of ***Eclipta prostrata*** (**A**) and ***Ludwigia peruviana*** (**B**) seeds incubated on filter papers moistened with solutions having different osmotic potentials at different temperature regimes in light/dark condition. Black bars, 0 MPa; grey bars, -0.5 Mpa; white bars, -1 MPa; dotted bars, -2 MPa. Different uppercase letters indicate significant differences between different incubation temperatures on the same osmotic potentials. Different lowercase letters indicate significant differences between osmotic potentials at the same incubation temperatures. Error bars are + SD.

families reported producing seeds with PY (Baskin *et al.*, 2000). Thus, experiments were conducted to determine the presence or absence of PY of seeds of these two species. Manually scarified seeds of these two species increased in mass significantly than the non-treated seeds during the imbibition. Thus, we concluded that seeds of *A. indica* and *M. corchorifolia* have PY. Further, during the germination test manually scarified seeds of these two species germinated to > 90 %, while intact seeds germinated < 40 %. It confirmed the PY of *A. indica* and *M. corchorifolia* seeds. Moreover, all of the manually scarified seeds of both the species germinated within 24 hrs, suggesting that embryos of these seeds are non-dormant. Eastin (1983) and Chauhan and Johnson (2008b) have observed a high germination rate of manually scarified *M. corchorifolia* seeds and they stated that hard seed coat appears to be the primary mechanism of dormancy of the seeds of this species. Moreover, Jayasuriya *et al*. (2013) have shown that the seeds of *A. indica* have PY, while Hanna (1973) has reported the PY of seeds of *A. americana*. However, Hanna (1973) has concluded that the seed coat of *A. americana* inhibits water imbibition as well as the gas exchange. Manually scarified seeds of *A. indica* and *M. corchorifolia* germinated equally well in light/dark conditions and in complete darkness. Therefore, it revealed that their germination was not influenced by light. Jin *et al*. (2010) and Chauhan and Johnson (2008b) have also reported that the seed germination of *A. indica* and *M. corchorifolia*, respectively, was not affected by light.

None of the fresh *L. decurrens* seeds germinated in any of the tested temperatures. In contrast, at least a small portion of seeds of all the other species germinated at least at one of the tested temperatures. According to these results, it can be concluded that fresh *L. decurrens* seeds have high levels of primary seed dormancy. Although a small portion of *C. pilosus* seeds germinated at the tested temperatures, the germination percentages were < 20 %. Thus, *C. pilosus* seeds can also be considered as dormant seeds. However, germination percentages of both these species have increased significantly at 25 ºC after they were treated with GA_3. Nondeep and intermediate PD can be alleviated by GA_3 treatment (Baskin and Baskin, 2004 and 2014). Thus, it can be suggested that seeds of these two species have nondeep - intermediate PD. Further, after 5 months dry storage *C. pilosus* and *L. decurrens* seeds germinated to a significantly high percentage at each temperature compared to the germination percentage of fresh seeds confirming the reports by Oziegbe *et al*. (2010). They have reported that the 6 months old seeds of *L. decurrens* have shown significantly higher germination percentage compared to that of freshly dispersed seeds. Dry storage response of these seeds further confirms our conclusion of nondeep – intermediate physiological dormancy of *C. pilosus* and *L. decurrens* seeds where dry storage for < 6 months alleviate nondeep-intermediate physiological dormancy (Baskin and Baskin, 2004). Moreover, after 5 month- dry storage germination of *C. pilosus* seeds is highest at 25 °C compared to that at 15 and 35 °C. Thus, this dormancy release behaviour is similar to that of type III nondeep PD seeds i.e., during the dormancy alleviation, type III nondeep PD seeds first gain the ability to germinate at medium temperature conditions (Baskin and Baskin, 2004). Thus, we can conclude that seeds of *C. pilosus* have type III nondeep PD. In contrast, after 5 months dry storage *L. decurrens* seeds showed the highest germination percentage at 35 °C. Germination percentage at 25 °C was higher than that 15 °C. Thus, *L. decurrens* seeds seem to be behaving as those with Type II nondeep PD seeds. When dormancy of type II nondeep PD seeds alleviated they first gain the ability to germinate at high temperatures. Thus, we can conclude that *L. decurrens* seeds have type II nondeep PD.

Approximately 50 % of the *Fimbristylis miliacea* seeds germinated at 35 ºC, while at other two

temperatures the seed germination was significantly low (< 15 %). Therefore, it can be suggested that seeds of *F. miliacea* are conditionally dormant or 35 °C incubation may have broken the dormancy of this species. However, when seeds were kept for 24 hrs at 35 °C and transferred to 25 ºC, ~ 50 % of them germinated (data not shown). Thus, it revealed that 24 hrs incubation at 35 ºC breaks the seed dormancy in *F. miliacea* seeds. Hence, *F. miliacea* seeds need only a short period of warm stratification to break the dormancy. Therefore, it can be concluded that the seeds of *F. miliacea* have nondeep physiological dormancy. Chauhan and Johnson (2009b) have reported that the seeds of *F. miliacea* have low levels of primary dormancy because freshly harvested seeds germinated 81-94 %. They also observed that the germination was greater at the warmer temperatures (30/20 and 35/25 °C) than at the moderate temperatures (25/15 °C). Further, as reported by Pons and Schroder (1986), the germination of *Fimbristylis littoralis* is induced by high temperatures and only 1 hour at a higher temperature is sufficient to induce the germination. However, 5 months dry storage of *F. miliacea* seeds lost germinability at 35 °C. Thus, it seems that dry storage has induced the secondary dormancy of *F. miliacea* seeds. However, interestingly 5 months dry storage has slightly increased the germination of *F. miliacea* seeds at 25 °C.

Five months of dry storage has affected the seed dormancy of tested species in various ways. None of the *E. prostrata* seeds germinated after five-months dry storage at ambient laboratory temperature. Further, 5 months stored *E. prostrata* seeds were not viable, revealing that *E. prostrata* seeds lose viability when they were stored dry at ambient temperature conditions. Seed germination of *A. indica* and *M. corchorifolia* seeds has increased at all the incubated temperatures after the dry storage. However, their germination (= imbibed) percentages were significantly higher at 35 °C (> 80 %) than at the other tested temperatures. At other temperatures germination percentage of seeds of these two species was < 50 %. Therefore, it seems that 5-month dry storage is not the dormancy breaking treatment for *A. indica* and *M. corchorifolia* seeds. Probably 5 months dry storage has increased the sensitivity of these seeds to dormancy-breaking cues (high temperature [~ 35 °C] wet incubation). Thus, seeds of *A. indica* and *M. corchorifolia* seeds seem to be requiring two steps to break physical dormancy as observed in some other species producing seeds with PY (Taylor 1981 and 2005; Taylor and Revell, 1999; Jayasuriya *et al*., 2008a, b, c and 2009; Gama-Arachchige *et al*., 2013).

According to the results of the standard germination experiment, some amount of fresh seeds of all the species germinated in all the temperatures, except of *A. indica* and *M. corchorifolia* seeds, which germinated only at 15 °C and of *L. decurrens* seeds which germinated to 0 % at all temperatures tested. However, only ~ 45% of the *L. decurrens* seeds germinated when they incubated on GA_3 and the rest remain non-germinated although they were viable. Further, ~ 15% seeds of the two nondormant species (*E. prostrata* and *L. peruviana*) remained non-germinated although they were viable. This indicated the physiological heteromorphism of seeds of all the studied species. This is a bet-hedging strategy to cope with possible total reproductive loss in unpredictable environments (Simons and Johnston, 2006). Especially having physiological heteromorphism in seeds of weed species is adaptive advantage to escape weed control attempts conducted in several times during a cropping period.

As the initial germination tests on freshly harvested seeds revealed that *E. prostrata* and *L. peruviana* seeds were non-dormant and these two species also occur in rice fields possibly with high salinity (rice fields in coastal region), seeds of these two species were used in testing the effect of salinity on seed germination. Results of these experiments revealed that with the decreasing osmotic potential mediated by NaCl, the germination percentages of both the tested species reduced in all the tested temperatures. Zhou and Deckard (2005) reported that osmotic and salt stress can reduce, delay or prevent germination. A reduction in water availability, associated with the toxic effect of salts, interferes in the process of water absorption by seeds and this may influence germination. However, Salehifar *et al.* (2010) have shown that the effect of NaCl on germination is mainly a result of its osmotic effect. Therefore, it can be suggested that the main factor that caused the reduction of seed germination of *E. prostrata* and *L. peruviana* during our experiment is the osmotic effect. However, before coming into conclusions, further experiments are needed to test to determine the effect of osmotic potential on seed germination on these two species on polyethylene-glycol (Gharoobi *et al*., 2012). According to the tolerance for saline conditions seeds can be categorized into three broad categories; salinity tolerant seeds, salinity sensitive seeds and seeds of which the germination completely inhibited by the saline conditions (Hakim *et al*., 2011b). According to this broad classification, we can conclude that our two tested species are somewhat tolerant of the saline conditions. However, Chauhan & Johnson (2008a) have reported that *E. prostrata* had a high tolerance to saline conditions at the germination phase and also at the subsequent stages of growth. Further, Jacobs *et al*. (1993) have mentioned that soil salinity inhibited germination of fresh *L. peruviana* seeds. Results obtained during our research are contradictory to both these reports. Probably salinity tolerance level may vary with the variety too.

With the observations of this study, *Eclipta prostrata*

and *Ludwigia peruviana* were identified as non-dormant seed producing species. Seeds of *Aeschynomene indica* and *Melochia corchorifolia* have PY and *Fimbristylis miliacea*, *Cyperus pilosus* and *Ludwigia decurrens* produce seeds with nondeep PD. Further, it was revealed that *E. prostrata* and *L. peruviana* seeds require light for germination. Five-months dry storage reduced the viability of *E. prostrata* seeds while it did not affect the seed viability or germination of *L. peruviana*. Moreover, our experiments revealed that *A. indica* and *M. corchorifolia* seeds require two steps to break the dormancy under natural conditions and dry storage increased the sensitivity of seeds of these two species for dormancy breaking cues. Dry storage has further, increased the germinability of *L. decurrens* seeds only at high temperatures (35 °C). Five-months dry storage has alleviated the dormancy of *C. pilosus* seeds, while it induced the secondary dormancy in *F. miliacea* seeds. Experiments revealed that with the decreasing osmotic potential of the medium, reduced the germinability of non-dormant seeds of *E. prostrata* and *L. peruviana*. According to these observations, out of seven weed species studied, two produce non-dormant seeds while remaining species producing dormant seeds. Among dormant seed producing species, two produce PY seeds and other three species produce PD seeds.

Our study revealed that the rice field weed species produce seeds with different classes of dormancy which require species-specific dormancy breaking requirements. Thus, no common alleviation mechanism could be recommended to alleviate the weed seeds of rice fields. However, dry storage has reduced the viability of some study species while it increases the germinability of most of the others either by breaking dormancy or by increasing the sensitivity to dormancy breaking treatments. Thus, it can be suggested that the rice field should kept dry during the intercropping period and thereafter facilitate irrigation to allow non-dormant seeds to germinate and exhaust from soil seed bank. These emerging weed seedlings should be eliminated by mechanical control before rice cultivation for effective weed management.

ACKNOWLEDGMENTS

Authors acknowledge the contribution of the reviewers and editors in improving the manuscript to a high standard.

LITERATURE CITED

Ajaib, M. and Z.U.D. Khan 2010. *Melochia corchorifolia* L. of family Sterculiaceae: An addition to the flora of Pakistan. Biologia (Pakistan) **56**: 133-135.

Altom, J.V. and D.S. Murray 1996. Factors affecting *Eclipta* (*Eclipta prostrata*) seed germination. Weed Technol. **10(4)**: 727-731.

Aruna, C., D. Chaithra, C. Alekhya and N. Yasodamma 2012. Pharmacognostic studies of *Aeschynomene indica* L. Int. J. Pharm. Pharm. Sci. **4**: 1-13.

Baskin, C.C. and J.M. Baskin. 2014. Seeds: Ecology, Biogeography and evolution of dormancy and germination. 2nd edition. Academic Press. San Diego, CA, USA.

Baskin, J.M. and C.C. Baskin. 2004. A Classification System for Seed Dormancy. Seed Sci. Res. **14(1)**: 1-16.

Baskin, J.M., C.C. Baskin and X. Li. 2000. Taxonomy, anatomy and evolution of physical dormancy in seeds. Plant Spec. Biol. **15(2)**: 139-152.

Benech-Arnold, R.L., R.A. Saencheza, F. Forcellab, B.C. Kruka and C.M. Ghersaa. 2000. Environmental control of dormancy in weed seed bank in soil. Field Crops Res. **67(2)**: 105-122.

Bhinge, S.D., M.G. Hogade, C. Chavan, M. Kumbhar and V. Chature. 2010. In Vitro Anthelmintic activity of *Eclipta prostrata* L. against *Pheretima Psthuma*. Asian J. Pharm. Clin. Res. **3**: 229-230.

Chandrasena, J.P.N.R. 1988. Floristic composition and Abundance of Rice - Field Weeds in Four Low-Country wet Zone Districts of Sri Lanka. Trop. Pest Manag. **34(3)**: 278-287.

Chandrasena, J.P.N.R. 1997. An Illustrated Manual of Rice-Field Weeds in Sri Lanka, UNESCO: Man and the Biosphere Committee (MAB), Sri Lanka, Publication No. 19, Natural Resources, Energy and the Science Authority of Sri Lanka.

Chauhan, B.S. and D.E. Johnson. 2008a. Influence of Environmental Factors on Seed Germination and Seedling emergence of Eclipta (*Eclipta prostrata*) in a Tropical Environment. Weed Sci. **56(3)**: 383-388.

Chauhan, B.S. and D.E. Johnson. 2008b. Seed germination and seedling emergence of Nalta jute (*Corchorus olitorius*) and Redweed (*Melochia concatenate*): Important broadleaf weeds of the tropics. Weed Sci. **56(6)**: 814-819.

Chauhan, B.S. and D.E. Johnson. 2009a. *Ludwigia hyssopifolia* emergence and growth as affected by light, burial depth and water management. Crop Prot. **28(10)**: 887-890.

Chauhan, B.S. and D.E. Johnson. 2009b. Ecological studies on *Cyperus difformis*, *Cyperus iria* and *Fimbristylis miliacea*: three troublesome annual sedge weeds of rice. Ann. Appl. Biol. **155(1)**: 103-112.

Dharmaratne, P.G. and S.L. Ranamukaarachchi. 1991. Sensitivity of Rice to *Ludwigia decurren*s (L.). Tropical Agricultural Research **3**: 181-194.

Dyer, W.E. 1995. Exploiting weed seed dormancy and germination requirements through agronomic practices. Weed Sci. **43**: 498-503.

Eastin, E.F. 1983. Redweed (*Melochia corchorifolia*) germination as influenced by scarification, temperature and seeding depth. Weed Sci. **31**: 229-231.

Gama-Arachchige, N.S., J.M. Baskin, R.L. Geneve and C.C. Baskin. 2013. Quantitative analysis of the thermal requirements for stepwise physical dormancy-break in seeds of the winter annual *Geranium carolinianum* (Geraniaceae). Ann. Bot. **111(5)**: 849-858.

Gharoobi, B.M., M. Ghorbani and M.G. Nezhad. 2012. Effects of different levels of osmotic potential on germination percentage and germination rate of barley, corn and canola. Iran. J. Plant Physiol. **2**: 413-417.

Grierson, A. 1980. Asteraceae. In: Dassanayake, M.D. and Fosberg, F.R. (Eds.). A revised handbook to the flora of Ceylon volume I. Amerind Publishers, New Delhi, India.

Hakim, M.A., A.S. Juraimi, M.M. Hanafi, A. Selamat, M.R. Ismail and M.P. Anwar. 2011a. Weed Flora in Rice Field of Tanjong Karang Coastal area in Malaysia. J. Food Agric. Environ. **9**: 694-699.

Hakim, M.A., A.S. Juraimi, M.M. Hanafi, A. Selamat, M.R. Ismail and S.M.R. Karim. 2011b. Studies on seed germination and growth in weed species of rice field under salinity. J. Environ. Biol. **32:** 529-536.

Hanna, W.W. 1973. Effect of seed treatment and planting depth on germination and seedling emergence in *Aeschynomene americana* L. Crop Sci. **13(1)**: 123-124.

Harriman, N.A. 1994. Poaceae. In: Clayton, W., Fosberg, F.R. and Dassanayake, M.D. (Eds.). A revised handbook to the flora of Ceylon volume 8. Amerind Publishers, New Delhi, India.

Ismail, B.S. and A.B. Siddique. 2012. Allelopathic Inhibition by *Fimbristylis miliacea* on the Growth of the Rice Plants. Adv. Environ. Biol. **6**: 2423-2427.

Jacobs, S. W. L., F. Perrett, M. Brock, K. H. Bowmer, G. McCorkelle, J. Rawling, J. Sticker and G. R. Sainty. 1993. *Ludwigia peruviana*-description and biology. Proceedings of the 10th Australian weeds conferences and 14th Asian Pacific weed science society conference (eds. B. J. Wilson, J. T. Swarbrick), Brisbane, Australia, 6-10 September, pp225-228.

Jayasuriya, K.M.G.G., J.M. Baskin and C.C. Baskin. 2008a. Cycling of Sensitivity to Physical Dormancy-break in Seeds of *Ipomoea lacunosa* (Convolvulaceae) and Ecological Significance. Ann. Bot. **101(3)**: 341-352.

Jayasuriya, K.M.G.G., J.M. Baskin and C.C. Baskin. 2008c. Dormancy, germination requirements and storage behaviour of seeds of Convolvulaceae (Solanales) and evolutionary considerations. Seed Sci. Res. **18(4)**: 223-237.

Jayasuriya, K.M.G.G., J.M. Baskin, R.L. Geneve and C.C. Baskin. 2009. Sensitivity cycling and mechanism of physical dormancy break in seeds of *Ipomoea hederacea* (Convolvulaceae). Int. J. Plant Sci. **170(4)**: 429-443.

Jayasuriya, K.M.G.G., J.M. Baskin, R.L. Geneve, C.C. Baskin and C.T. Chien. 2008b. Physical dormancy in seeds of the holoparasitic angiosperm *Cuscuta australis* (Convolvulaceae, Cuscuteae): dormancy breaking requirements, anatomy of the water gap and sensitivity cycling. Ann. Bot. **102(1)**: 39-48.

Jayasuriya, K.M.G.G., A.S.T.B. Wijetunga, J.M. Baskin and C.C. Baskin. 2013. Seed dormancy and storage behaviour in tropical Fabaceae: a study of 100 species from Sri Lanka. Seed Sci. Res. **23(4)**: 257-269.

Jin, C.H., M.R. Uddin and J.Y. Pyon. 2010. Seed germination and seedling emergence of Indian jointvetch (*Aeschynomene indica* L.) in different conditions. Korean Journal of Weed Science **30(1)**: 25-33.

Khan, A.V. and A.A. Khan. 2008. Ethnomedicinal Uses of *Eclipta prostrata* Linn. Indian J. Tradit. Knowl. **7**: 316-320.

Kon, K.F., G.B. Follas and D.E. James. 2007. Seed dormancy and Germination phenology of grass weeds and implications for their control in cereals. N. Z. Plant Prot. **60**: 174-182.

Odero, D.C. and C. Rainbolt. 2011. 'Weed management in rice.' (Agronomy Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida: Gainesville, FL, USA.

Oziegbe, M., J.O. Faluyi and A. Oluwaranti. 2010. Effect of seed age and soil texture on the germination of some *Ludwigia* species (Onagraceae) in Nigeria. Acta Bot. Croat. **69:** 249-257.

Pons, T.L. and H.F.G.M. Schroder. 1986. Significance of temperature fluctuation and oxygen concentration for germination of the rice field weeds *Fimbristylis littoralis* and *Scirpus juncoides*. Oecologia **68(2)**: 315-319.

Pullaiah, T. 2014. Ethnobotany, Phytochemistry and Pharmacology of *Melochia corchorifolia* L. Int. Res. J. Pharm. **5(7)**: 543-545.

Rajapakse, R., N. Chandrasena, B. Marambe and L. Amarasinghe. 2012. Planning for Effective Weed Management: Lessons from Sri Lanka. Pakistan Journal of Weed Science Research **18**: 843-853.

Rao, B.G., Y.V. Rao and T.M. Rao. 2013. Hepatoprotective and Antioxidant Capacity of *Melochia corchorifolia* extracts. Asian Pac. J. Trop. Med. **1**: 537-543.

Rudd, V.E. 1991. Fabaceae. In: Dassanayake, M.D. and Fosberg, F.R. (Eds.). A revised handbook to the flora of Ceylon volume 7. A.A. Balkema Publishers, Rotterdam, Netherlands.

Salehifar, M., A. Torang, M. Farzanfar and M. Salehifar. 2010. Comparison of salinity stress effect on germination and seedling growth in 8 lines genotypes of common bean (Phaseolus vulgaris). 11th Iranian Crop Science Congress, p. 3794.

Sangakkara, U.R., S.P. Nissanka, B. Marambe, K. Hurle and B. Rubin. 2004. Weeds, Herbicide use and Resistance in Rice Fields in Sri Lanka, 4th International Crop Science Congress, Brisbane, Australia. 26 September-1 October.

Simons, A.M. and M.O. Johnston. 2006. Environmental and genetic sources of diversification in the timing of seed germination: implications for the evolution of bet hedging. Evolution **60(11)**: 2280-2292.

Steinbaeur, G.P. and B. Grigsby. 1957. Interaction of Temperature, light and Moisturizing Agent in the germination of Weed Seeds. Weeds **5(3)**: 175-182.

Taylor, G.B. 1981. Effect of constant temperature treatments followed by fluctuating temperatures on the softening of hard seeds of *Trifolium subterraneum* L. Aust. J. Plant Physiol. **8(6)**: 547-558.

Taylor, G.B. 2005. Hardseedness in Mediterranean annual pasture legumes in Australia: a review. Aust. J. Agric. Res. **56(7)**: 645-661.

Taylor, G.B. and C.K. Revell. 1999. Effect of pod burial, light, and temperature on seed softening in yellow serradella. Aust. J. Agric. Res. **50(7)**: 1203-1209.

Wilson, B.J. and J.T. Swarbrick. 1993. *Ludwigia peruviana*, description and biology. Proceedings I of the 10th Australian Weeds Conference and 14th Asian Pacific Weed Science Society Conference, Brisbane, Australia, 6-10 September, 1993 pp. 225-228.

Zhou, J. and E.L. Deckard. 2005. Factors affecting eastern black nightsho (*Solanum ptycanthum*) seed germination. Weed Sci. **53(5)**: 651-656.