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Article

PHENOLICS IN TWO *Alternanthera* SPECIES RESIDUES AFFECT THE GERMINATION AND EARLY SEEDLING GROWTH OF RICE (*Oryza sativa*)

*Fenóis Totais em Resíduos de Duas Espécies de **Alternanthera** Afetam a Germinação e o Crescimento das Plântulas de Arroz (**Oryza sativa**)*

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ABSTRACT - *Alternanthera* species are invasive aquatic/semi-aquatic weeds posing a serious threat to agro-biodiversity in several countries in the world. The present study was conducted to assess the phytotoxic effects of *Alternanthera philoxeroides* and *A. sessilis* residues on emergence and early seedling growth traits of rice (*Oryza sativa*). Soil was prepared with 4% (w/w) *Alternanthera* species residues separately and allowed to decay for 0, 15 and 30 days. Rice emergence was significantly decreased but increase in mean emergence time and time to 50% emergence was observed in soils modified with *Alternanthera* species residues compared with seed sown in unmodified soils. Rice emergence was reduced to 50-67% and 52-75% by *A. sessilis* and *A. philoxeroides*, respectively. A significant reduction in rice root, shoot length, and biomass was also noted with *Alternanthera*-infested soil. Total phenolics increased with increasing residue decay time in both species thereby showing their direct interaction with emergence and seedling traits of rice. The phenolic compounds identified were namely Quercitin, Chlorogenic acid, P-Coumeric acid, Trans-4-hydroxy3-methoxy, Cinamic acid, Caffeic acid, Syringic acid, Sinapic acid, Vanillic acid, 4-hydroxy-3-methoxy benzoic acid.

Keywords: allelopathy, *Alternanthera*, rice, seedling growth, decomposition periods.

*RESUMO - As espécies do gênero **Alternanthera** são plantas daninhas aquáticas/semiaquáticas invasoras que representam uma ameaça grave para a agrobiodiversidade em diversos países do mundo. O presente estudo foi realizado para avaliar os efeitos fitotóxicos dos resíduos de **Alternanthera philoxeroides** e **A. sessilis** nas características de emergência e crescimento inicial de plântulas de arroz (**Oryza sativa**). O solo foi preparado com resíduos de espécies de **Alternanthera** – 4% (w/w) – separadamente, que foram submetidas a um período de decomposição de 0, 15 e 30 dias. Houve redução significativa da emergência do arroz, porém foi observado aumento no tempo médio de emergência e no tempo para emergência de 50% em solos modificados com resíduos de espécies de Alternanthera, em comparação com sementes semeadas em solos não modificados. A emergência do arroz com **A. sessilis** e **A. philoxeroides** foi reduzida para 50-67% e 52-75%, respectivamente. Uma redução significativa do comprimento da raiz do arroz, da parte aérea e da biomassa também foi observada no solo infestado com as espécies de **Alternanthera**. Também ocorreu aumento dos fenólicos totais à medida que aumentou o tempo de decomposição dos resíduos em ambas as espécies, mostrando, assim, interação direta com as características de emergência e crescimento de plântulas de arroz. Foram identificados os compostos fenólicos quercetina, ácido clorogênico, ácido p-cumárico, trans-4-hidroxi-3-metoxi, ácido cinâmico, ácido cafeico, ácido siríngico, ácido sinápico, ácido vanílico e ácido benzoico 4-hidroxi-3-metoxi.*

Palavras-chave: alelopatia, *Alternanthera*, arroz, crescimento de plântulas, períodos de decomposição.

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INTRODUCTION

Weeds are one of the major problems in crop production (Marwat et al., 2008) as they compete with crop plants for nutrients, moisture, light, space, growth requirements, and exert allelopathic effects on crop seed germination and growth by releasing water-soluble compounds into the soil (Batish et al., 2007b; Kumar et al., 2009). A wide range of injurious effects on crop growth has been reported as a result of phytotoxic decomposing products, released from leaves, stem, roots, fruit and seeds (Khan et al., 2009). The allelopathic effect of a weed on crops can be ascertained by measuring their germination and growth, a technique known as plant bioassay. The extent of allelopathic inhibition on germination and seedling growth of crops varies with weed species (Hamayun et al., 2005). Most of the weed species have inhibitory effects on crops; yet some weed species also exhibit stimulatory effects. Studies have reported inhibitory effects of phenolics from aquatic weeds on germination, seedling growth and total biomass of wheat (Abbas et al., 2014).

Rice is an important staple food and cash crop in different countries in the world. It is estimated that average crop losses caused by weeds worldwide are 9.5% (Alam, 2003). In severe cases, yield losses may amount to more than 50%, depending on density, species, time of weed germination, weed infestation duration, space available for growth and other management practices (BRRI, 2006). Some emerging invasive weeds of rice are *A. sessilis* and *A. philoxeroides*, which seem to be more proliferating and problematic than existing weeds. *Alternanthera philoxeroides* and *A. sessilis* are commonly known as alligatorweed and sessile joyweed, respectively which belong to the family Amaranthaceae. *Alternanthera philoxeroides* is a perennial species that rarely sets seeds (Julien, 1995). It is known as an invasive species in many parts of the world (Julien et al., 1995), and it has a tremendous potential for vegetative reproduction (Julien et al., 1995; Sainty et al. 1998; Clements et al., 2011). It has the ability to grow in both aquatic and terrestrial habitats and in conservation and agricultural systems of tropical, subtropical and temperate regions (Julien and Stanley, 1999). *Alternanthera philoxeroides* is a noxious weed in Brazil (Barreto and Torres, 1999), Australia (Julien and Bourne, 1988; Milvain et al., 1995; Krake et al., 1999), New Zealand, UK (Arthington and Mitchell, 1986) and USA (Rhodes and Demont, 1983). *Alternanthera philoxeroides* is a problem weed in 10 crops in 30 countries, a serious or principal weed in eight of these countries and a major weed in others. In China, *A. philoxeroides* has been recognized as an invasive and troublesome weed in rice, corn, cotton, soybean (Lu et al., 2002; Ye et al., 2003) wheat, sweet potatoes, vegetables, and fruit trees (Tan, 1994a,b).

Alternanthera philoxeroides has the potential to devastate natural systems, agricultural areas and recreational areas through its interference and spread by human activities. It is competitive with other plant species, forms monocultures, and is not constrained by natural enemies or other environmental constraints that exist in its native range (Bassett, 2009). The allelopathic potential of *A. philoxeroides* in its successful invasion of new areas has been reported by Xie et al. (2010). Paria and Mukharjee (1981) reported that *A. philoxeroides* contains allelopathic potential and complete inhibition of rice germination, and seedling growth was noted at 1:2.5 concentrations. *Alternanthera philoxeroides* caused 60% reduction in total biomass of wheat seedling (Abbas et al., 2014). Yong et al. (2011) reported inhibitory effects of *A. philoxeroides* in different field crops. In China, crop production was reduced by 20 to 63 percent due to *A. philoxeroides* (Ensbey, 2001) while *A. philoxeroides* invasion may lead to yield losses of up to 45% for some horticultural crops (Shen et al., 2005). In pasture ecosystems, *A. philoxeroides* steadily increases in biomass and displaces other species (Julien and Bourne, 1988). Aqueous extracts of *A. philoxeroides* inhibited the germination and seedling development of ryegrass (Zhang et al., 2009).

Alternanthera sessilis exists as a noxious weed in both wetlands and uplands (Soerjani et al., 1987), and it can grow on a variety of soil types. Reproduction in *A. sessilis* occurs by seeds. *Alternanthera sessilis* is the predominant weed of rice in Taiwan and causes moderate yield and quality losses, and it is economically important in certain other rice producing countries (Chiang and Leu, 1981). Abbas et al. (2014) reported that the water extract of *A. philoxeroides* and *A. sessilis* reduced up to 60% germination, seedling growth and total biomass of wheat. Information about alleopathic and residue decomposition effects of *A. sessilis* and *A. philoxeroides* on rice is lacking. It is hypothesized; that *Alternanthera* residues may hinder the germination and seedling growth traits of rice plants by releasing water soluble allelochemicals. Therefore, the objective of the study was to assess the phytotoxicity of *A. sessilis* and *A. philoxeroides* decomposed residues on germination and early seedling growth of rice.

MATERIALS AND METHODS

Collection of plant materials

Fully grown plants of *A.philoxeroides* and *A. sessilis* from an infested area were collected in 2013. These were separated into root, shoot, leaf, flower (only in *A. sessilis*) and whole plant fractions. These plant parts were cut into small pieces (2-3 cm) with a pair of scissors and air dried for a month under shade with mean temperature of 20 °C and relative humidity of 55%. The dried plant fractions were stored in plastic bags at room temperature before they were used for the experiments. For bioassay studies, certified seeds of rice variety "Basmati-515" were used.

Treatments and experimental design

There were seven treatments for the germination bioassay, arranged in a completely randomized design with four replications. The treatments included control, *A. sessilis* (0, 15 and 30 days decomposition) and *A. philoxeroides* (0, 15 and 30 days decomposition). Maximum and minimum temperatures during the course of the experiment were 35.1 °C and 33.8 °C, respectively.

Seedling emergence and growth bioassay with *Alternanthera* residues decomposed for 15 and 30 days

In order to simulate natural conditions, a study was conducted in which concentrations of 1, 2, 3, 4, and 5% (w/w) of *A. philoxeroides* and *A. sessilis* residues were mixed in 250 g soil for each *Alternanthera* species, separately. It was found that there was no rice germination at the 5% (w/w) concentration for either species. Hence a new study was planned to study the germination and seedling growth of rice using 4% residues of *Alternanthera* species. In the present study, 8 g residues of both *Alternanthera* species were mixed into the soil of filled plastic pots of 10 cm diameter and 10 cm depth to get 4% (w/w) for each *Alternanthera* species separately. Then 100 mL of distilled water was added to each pot and left at room temperature to decompose the residues for 0, 15, and 30 days. In control, only 200 g of unmodified soil was used. Ten seeds of rice were sown simultaneously in each plastic pot. In order to determine the type and amount of phenolic compounds in the soil with decomposed residues, separate pots with the same amount of weed residues of both weed species were placed and allowed to decompose for 15 and 30 days. All the pots were placed on a laboratory bench. The samples were taken from the pots having only weed residues of both weed species decomposed for a period of 15 and 30 days and analyzed for determination of phenolic compounds.

Data collection and statistical analysis

Mean Germination Time (MGT) was calculated with the equation of Ellis and Roberts (1981).

$$MGT = \Sigma Dn/\Sigma n$$

where n is the number of seeds that had germinated on day D and D is the number of days counted from the beginning of germination.

Time taken to 50% germination (T_{50}) was calculated by using the formula given by Coolbear et al. (1984) as modified by Farooq et al. (2004).

$$T_{50} = t_i + \frac{\left\{\left(\frac{N}{2}\right) - n_i\right\}(t_j - t_i)}{(n_j - n_i)}$$

where N is the final number of germinated seeds while n_j and n_i are the cumulative number of seeds germinated by adjacent counts at times t_j and t_i, respectively, where $n_i < N/2 < n_j$. Germination index (GI) was calculated as given by the Association of Official Seed Analysis (AOSA, 1990). Germination was calculated by counting and removing the germinated seeds. Germination was observed daily in accordance with the methods of the Association of Official Seed Analysis (AOSA, 1990).

Total soluble phenolics were determined as described by Randhir and Shetty (2005) and were expressed as gallic acid equivalents (Figure 2). For identification and quantification of their suspected phytotoxins, aqueous extracts were chemically analyzed (Table 3) on Shimadzu HPLC system (Model SCL-10A, Tokyo, Japan). The peaks were detected by UV detector. Standards of suspected phytotoxins (Aldrich, St Louis, USA) were run similarly for their identification and quantification. Concentration of each isolated compound was determined by the following equation.

$$Concentration\,(ppm) = \frac{Area\ of\ the\ sample}{Area\ of\ the\ standard} \times Concentration\ of\ the\ standard \times Dilution\ factor$$

Seedling vigor index (SVI) was calculated by using the following formula of Abdul-Baki and Anderson (1973).

SVI = germination/emergence% × radicle length

Each experiment was repeated twice. The average data obtained from each experiment were subjected to analysis of variance using the computer software statistix 8.1. The treatment means were grouped on the basis of least significant difference at the 0.05 level of probability (Steel et al., 1997).

Regression analyses as well as the figures were completed using the software Minitab 16 (Minitab, State College, PA) in which linear, quadratic and cubic components were successively tested for significance and included if the residual sum of squares were significantly reduced ($p<0.05$). The most appropriate regression model between decomposition duration (*Alternanthera sessilis* and *Alternanthera philoxeroides*) and mean emergence time, emergence percentage, shoot length, shoot dry weight, root length and root dry weight was the second order quadratic one (Equation 1).

$$Y = \beta_0 + \beta_1 x + \beta_2 x^2 + \beta_3 x^3 + \varepsilon \qquad \text{(eq. 1)}$$

where Y is the dependent (response) variable, x is the independent variable, and the error term ε is assumed to have normal distribution with constant variance. For each response, the validity of model assumptions was verified by examining the residuals as described in Montgomery (2009). Contour plots of shoot dry weight and root dry weight for mean emergence time (days) and seedling vigour index of rice were constructed using the software Minitab 16 (Minitab, Sate College, PA)

RESULTS AND DISCUSSION

Data in Table 1 show that *Alternanthera sessilis* and *A. philoxeroides* modified soil significantly and affected the time taken to 50% seed emergence (T_{50}) and mean emergence time (MET). Both were significantly increased in comparison with unmodified soil (Table 1). The highest emergence index (EI) value was recorded in unmodified soil, which was significantly higher than the values of all other treatments, while the lowest values of EI were recorded in treatments where *Alternanthera* species residues were allowed to decompose for 30 days. The contrast *Alternanthera sessilis* vs *A. philoxeroides* for MET and the contrast 0 vs 15 days weed residue decomposition for EI were non significant. The remainder of rice seed germination traits showed significant differences for *A. sessilis* vs *A. philoxeroides*, for the durations of 0 vs 15, 0 vs 30 and 15 vs 30 day residues decomposition. Figure 1 shows that emergence (%) of rice was significantly affected by both weed species residues and drastically reduced by increasing the duration of weed residue decomposition. Our study indicates that *Alternanthera* residues have inhibitory effects on emergence of rice seedlings and there was an increase in phytotoxicity with increased duration of *Alternanthera* residue decomposition. It could be related to release of more allelochemicals and their availability in soil. These results are supported by the findings of Tanveer et al. (2010).

Table 1 - Effect of duration of *Alternanthera* residue decomposition on emergence traits of rice

Treatment	Mean emergence time (days)	Time to 50% germination (days)	Emergence index
Control (No residue)	5.90 e	5.73 e	1.85 a
A. sessilis with zero days decomposition	9.19 d	8.21 d	0.59 b
A. sessilis with 15 days decomposition	10.18 a	9.02 c	0.57 b
A. sessilis with 30 days decomposition	9.70 b	9.75 b	0.33 cd
A. philoxeroides 0 days decomposition	9.45 c	9.22 c	0.41 c
A. philoxeroides 15 days decomposition	9.56 bc	10.19 a	0.53 c
A. philoxeroides 30 days decomposition	10.19 a	10.25 a	0.24 d
LSD at $p \leq 5\%$	0.140	0.216	0.117
Contrasts			
Control vs all	5.90 vs 9.71**	5.73 vs 9.44**	1.85 vs 0.44**
A. sessilis vs *A. philoxiroides*	9.69 vs 9.73^{NS}	8.99 vs 9.89**	0.50 vs 0.39**
0 vs 15 days decomposition	9.32 vs 9.87**	8.71 vs 9.60**	0.50 vs 0.55 ^{NS}
0 vs 30 days decomposition	9.32 vs 9.95 **	8.71 vs 10.00**	0.50 vs 0.29**
15 vs 30 days decomposition	9.87 vs 9.95*	9.60 vs 10.00**	0.55 vs 0.29**

Means sharing the same letters in a column do not differ significantly at the 0.05 probability level according to the LSD test. * Comparisons are significant at the $p \leq 0.05$ level of probability. ** Comparisons are significant at the $p \leq 0.01$ level of probability. NS = Non-significant.

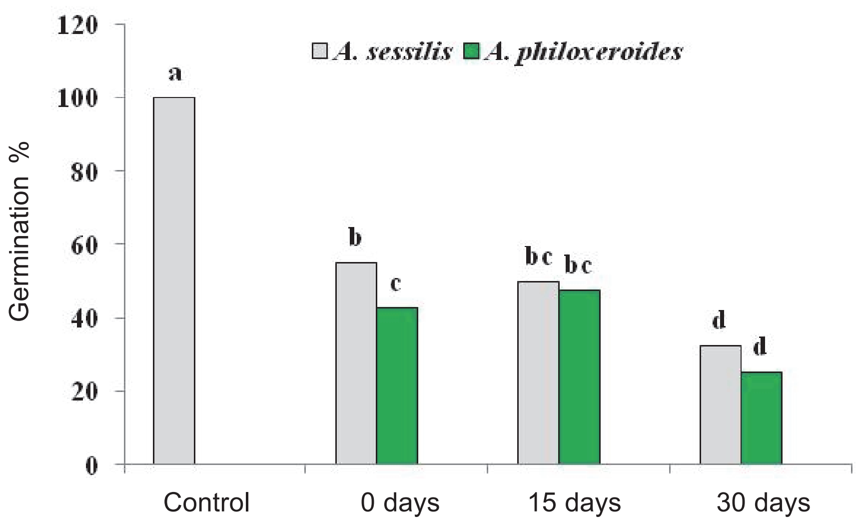

Figure 1 - Effect of duration of *Alternanthera* residue decomposition on emergence % of rice.

They recorded significant reduction in emergence of wheat, chickpea and lentil in *Euphorbia helioscopia* infested soil.

Delayed emergence might be due to the production of the phenolic compound vanillic acid, which has inhibitory effect on germination (Ali et al., 2013). Although emergence was delayed with the decomposition period of 30 days, it occurred much earlier than the 15-day decomposition period. This can be attributed to the different phenolic produced at these two decomposition periods. The differences in the emergence time of rice for the two *Alternanthera* species can be due to production of more phenolics by *A. philoxeroides* than *A. sessilis* (Table 3).

Alternanthera sessilis and *A. philoxeroides* residues, after the decomposition period of 15 days, enhanced root length, shoot length, root dry weight, shoot dry weight and seedling vigor index (SVI) of rice as compared to other treatments except for the control (Table 2). A significant inhibitory effect of *A. sessilis* and *A. philoxeroides* on rice seedling root, shoot length and their dry weights were recorded when these weed residues were allowed to decompose for zero and 30 days. The contrast comparison between control vs all periods was highly significant for root, shoot length, their dry weights and SVI whereas it was non-significant between both weed species for root dry

Table 2 **-** Effect of duration of *Alternanthera* residue decomposition on seedling growth of rice

Treatment	Root Length (cm)	Shoot length (cm)	Root dry weight (g)	Shoot dry weight (g)	Seedling vigor index
Control (No residue)	3.96 a	13.12 a	8.12 a	30.96 a	396.00 a
A. sessilis (0 day decomposition)	2.46 d	9.54 c	5.13 cd	22.13 b	135.44 b
A. sessilis (15-day decomposition)	2.68 bc	9.72 bc	5.68 b	22.16 b	134.12 b
A. sessilis (30-day decomposition)	2.15 e	7.25 d	4.28 e	16.10 d	69.82 c
A. philoxeroides (0 day decomposition)	2.54 cd	9.65 bc	4.93 d	21.04 c	107.80 b
A. philoxeroide (15-day decomposition)	2.75 b	9.82 b	5.64 bc	22.00 b	130.55 b
A. philoxeroide (30-day decomposition)	2.22 e	7.34 d	4.75 de	16.44 d	55.71 c
LSD at p ≤ 5%	0.175	0.212	0.511	0.704	27.68
Control vs all	3.96 vs 2.47**	13.12 vs 8.89**	8.12 vs 5.07**	30.96 vs 19.98**	396.00 vs 105.57**
A. sessilis vs *A. philoxiroides*	2.43 vs 2.50*	8.84 vs 8.94*	5.03 vs 5.11^{NS}	20.13 vs 19.83*	113.13 vs 98.02**
0 vs 15-day decomposition	2.50 vs 2.72	9.60 vs 9.77**	5.03 vs 5.66**	21.58 vs 22.08**	121.62 vs 132.34^{NS}
0 vs 30-day decomposition	2.50 vs 2.19**	9.60 vs 7.30**	5.03 vs 4.52**	21.58 vs 16.27**	121.62 vs 62.77**
15 vs 30-day decomposition	2.72 vs 2.19**	9.77 vs 7.30**	5.66 vs 4.52**	22.08 vs 16.27**	132.43 vs 62.77**

Means sharing the same letters in a column do not differ significantly at the 0.05 probability level according to the LSD test. * Comparisons are significant at the $p \leq 0.05$ level of probability. ** Comparisons are significant at the $p \leq 0.01$ level of probability. NS = Non-significant.

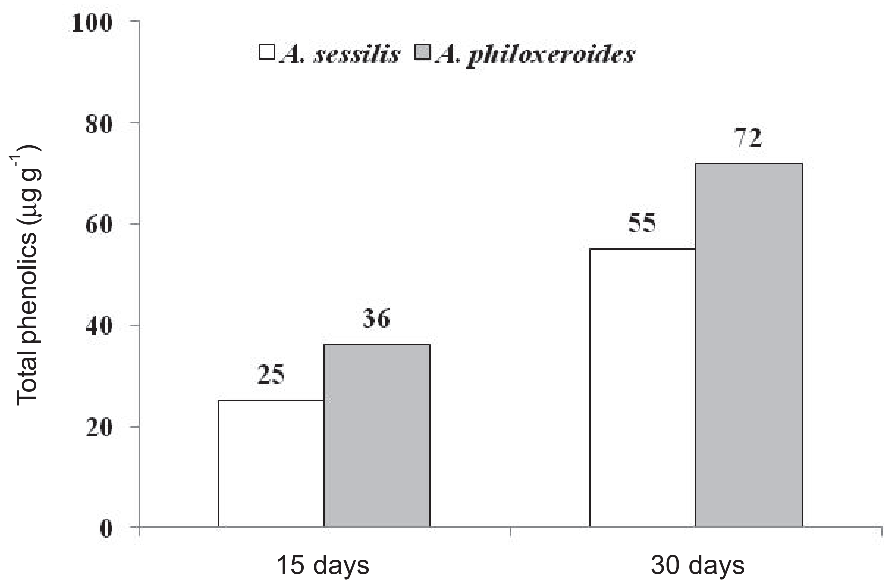

Figure 2 **-** Release of total phenolics by *Alternanthera* residues after different decomposition durations.

weight. The contrast comparison between 0 vs 15-day decomposition was non-significant for SVI of rice. Contrasts between 0 vs 30 and 15 vs 30-day residue decomposition were significant for all seedling growth parameters (Table 2). These results indicate that *Alternanthera* residues release growth retardatory substances into the soil, which accumulate in bioactive concentrations and adversely affect the growth of rice seedlings. Increase in seedling growth of rice at 15-day decomposition duration of *A. sessilis* and *A. philoxeroides* residues could be attributed to the presence of allelochemicals which had stimulatory effect (Kadioglue et al., 2005).

The relationship between decomposition duration (*A. sessilis* and *A. philoxeroides*) and rice responses (mean emergence time, emergence percentage, shoot length, shoot dry weight, root length and root dry weight) was adequately described by the second order polynomial regression model, whose relationship between decomposition duration and rice responses was very strong (R^2 ranges from 0.84 to 0.99), suggesting that the fitted models shown in Figures 3 and 4 can be used to predict rice responses at decomposition duration from 0 to 30 days.

Table 3 **-** Water soluble phenolics identified in *Alternanthera* residue extracts

Sr. No.	Phenolics	Concentration (mg L^{-1})			
		After 15 days		After 30 Days	
		A. sessilis	*A. philoxeroides*	*A. sessilis*	*A. philoxeroides*
1	Quercitin	0.111	0.10	0.104	0.113
3	Chlorogenic acid				12.24
4	P- Coumeric acid			2.45	2.79
5	Trans-4-hydroxy3-methoxy cinamic acid			12.56	45.22
6	Caffeic acid		5.38		
7	Syringic acid		10.75	7.625	
8	Sinapic acid		7.82		
9	Vanillic acid	3.72			
10	4-hydroxy-3-methoxy benzoic acid			18.12	
Total		3.831	24.05	40.86	60.363

Mean emergence time of rice increased with decomposition duration of *A. sessilis* from 0 to 15 days and decreased from 15 to 30 days (Figure 3A). However, in case of *A. philoxeroides*, mean emergence time of rice continued to increase from 0 to 30 days of decomposition duration (Figure 4A). There was a strong relationship between emergence percentage (decreased) of rice and decomposition duration of *A. sessilis* from 0 to 30 days analyzed through regression (Figure 3B). Decomposition duration (0 to 15 days) of *A. philoxeroides* increased emergence percentage of rice but emergence percentage decreased from 15 to 30-day duration (Figure 4B). Shoot length, shoot dry weight, root length and root dry weight of rice increased with the increasing decomposition duration (0-15 days) of *A. sessilis* and *A. philoxeroides* and steeply decreased from 15 to 30 days, exhibiting a strong quadratic relationship (Figs. 3C, 3D, 3E, 3F, 4C, 4D, 4E and 4F). Allelochmicals have potential to stimulate growth at their lower concentrations. It may possible that by increasing the time of decomposition, the concentration of allelochemicals was increased from lower to higher. After fifteen days, lower concentration of allelochmicals might be equated with stimulatory doses. At zero days, no allelochemicals were released,; however, 15 days after decomposition, allelopathic effects may be stimulatory or inhibitory (Torres et al., 1996); most of the allelochemicals produced inhibitory effects at higher concentrations and stimulated growth at lower concentrations (Saleh and Madany, 2013; Hernandez-aro et al., 2016)

The contour plot (Figure 5) showed how seedling vigor index (y) and mean emergence time (x) affect the shoot/root dry weight (contours) of rice. The darker regions indicate higher shoot/ root dry weight. The contour levels reveal a peak centered in the vicinity of 6 days (mean emergence time) and 390 (seedling vigor index). Shoot and root dry weights in this peak region are greater than 30 g and 8 g, respectively. The seedling exhibiting higher vigor index emerged earlier and had more time for accumulating root and shoot biomass. The increase in root and shoot biomass with increased mean emergence time has been reported by Mehmood et al. (2014).

The present study indicates that rice can grow well under normal conditions of soil but is sensitive to soil amendment with *Alternanthera* residues. The reduction in emergence, seedling length, dry weight and increase in emergence time of rice seedlings could be attributed to the presence of phytotoxic phenolics in the amended soil. These have been identified as Quercitin, Chlorogenic acid, P-Coumaric acid, Trans-4-hydroxy3-methoxy cinamic acid, Caffeic acid, Syringic acid, Vanillic acid, and 4-hydroxy-3-methoxy benzoic acid (Table 3).

Furthermore, total released phenolics significantly increased (from 25 to 55 μg g^{-1} in *A. sessilis* and 36 to 72 μg g^{-1} in *A. philoxeroides*) with increasing duration of *Alternanthera* residue decomposition (Figure 2). The presence of significantly higher amounts of phenolics after 30 days of decomposition of *Alternanthera* residues may be responsible for more reduction in rice seed emergence and seedling traits than those of 15-day decomposition. These results are in contradiction with those of Mersie and Singh (1987), who stated that toxicity of *Parthenium* residues

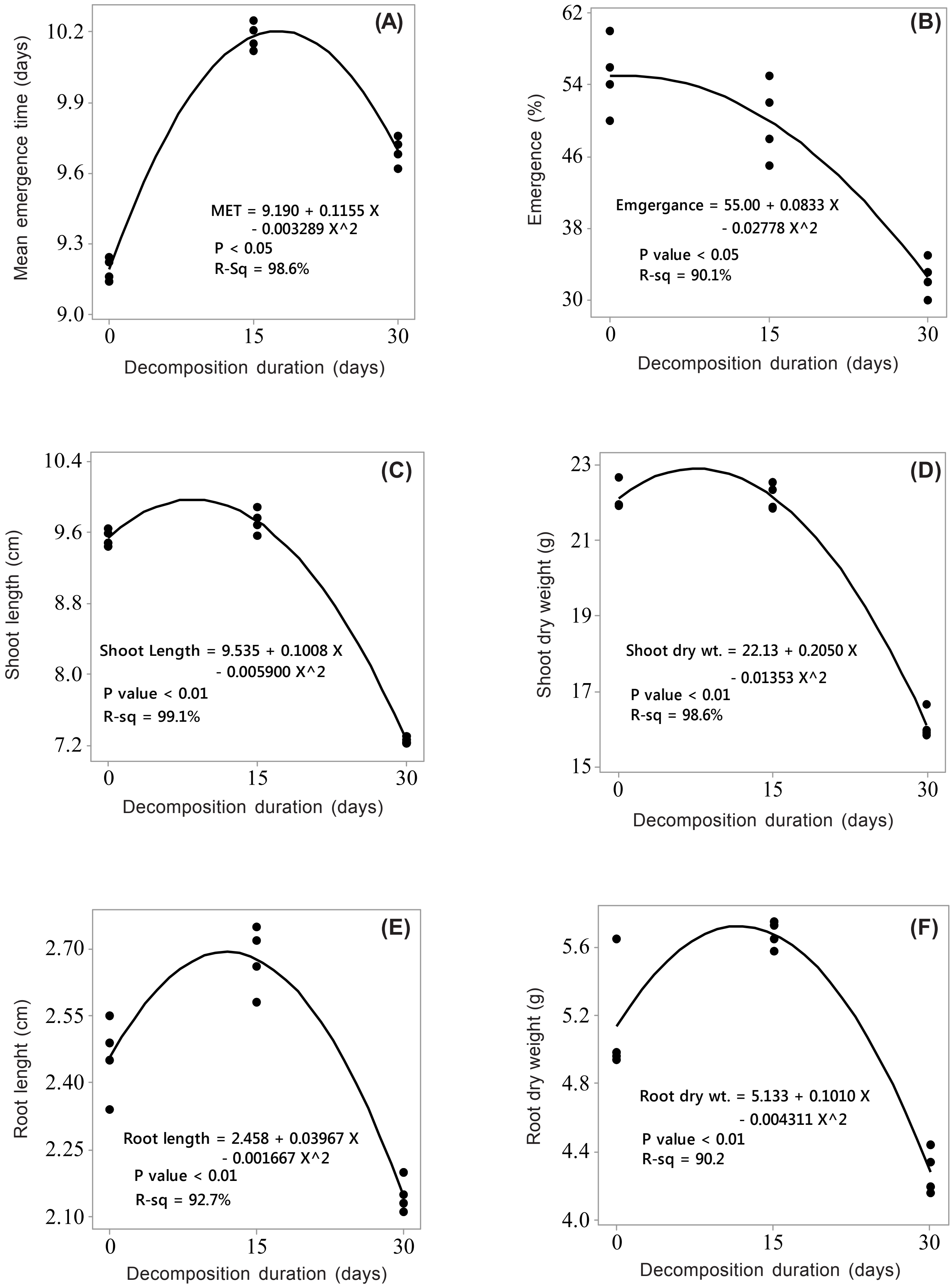

Figure 3 - Effect of decomposition duration of *Alternanthera.sessilis* on mean emergence time, emergence (%), shoot/root length and shoot/root dry weight of rice. The plots were fitted with second order polynomial regression models. Equations of the fitted models, *P*-values and R^2 values are shown within each plot.

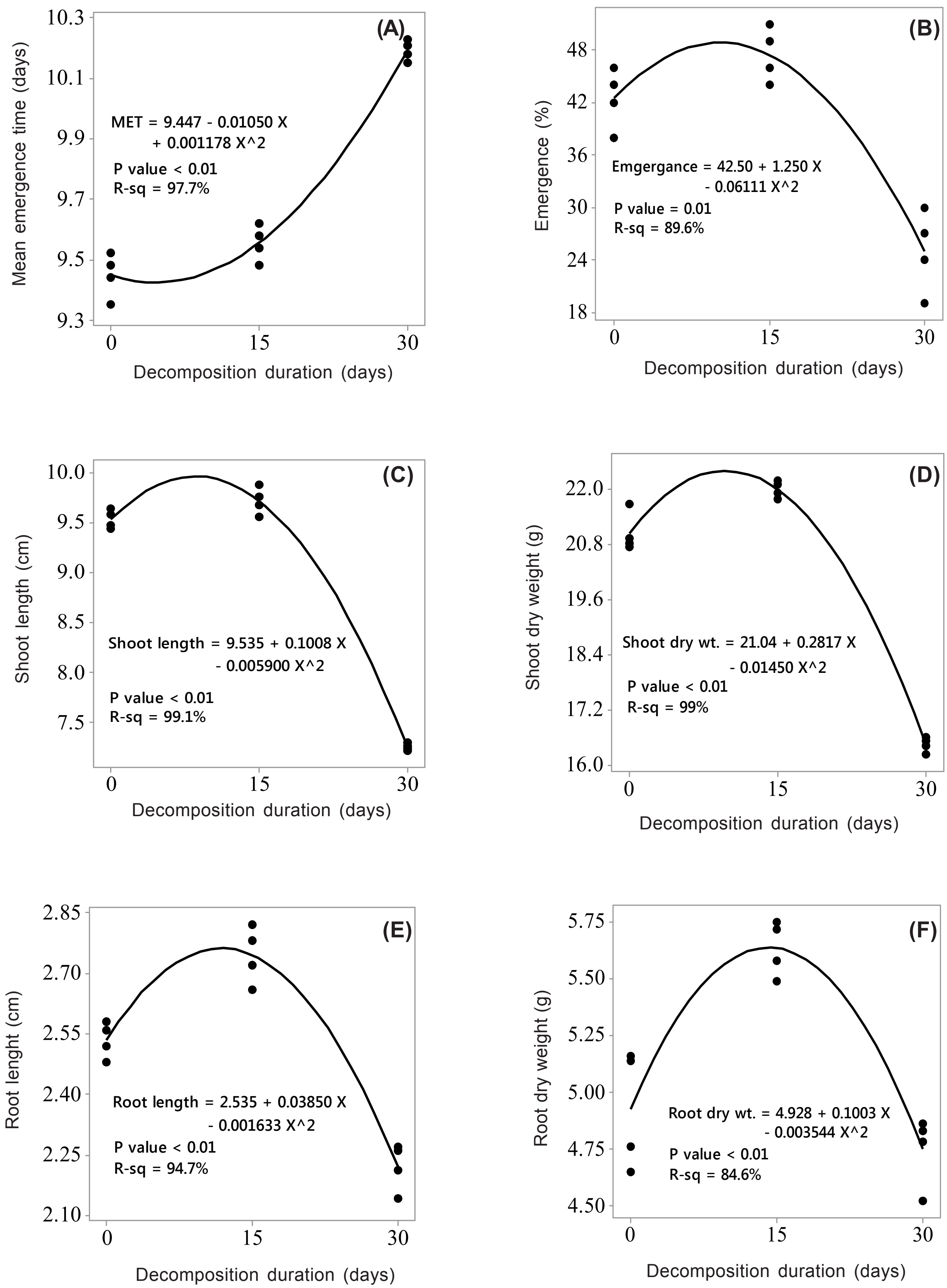

Figure 4 - Effect of decomposition duration of *Alternanthera.philoxeroides* on mean emergence time, emergence (%), shoot/root length and shoot/root dry weight of rice. The plots were fitted with second order polynomial regression models. Equations of the fitted models, *P*-values and R^2 values are shown within each plot.

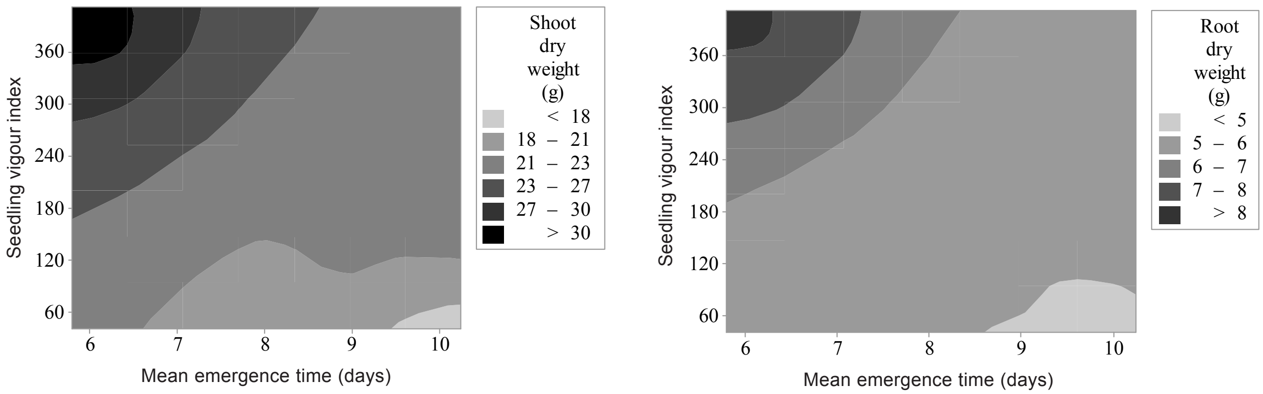

Figure 5 - Contour plot of shoot dry weight (A) and root dry weight (B) for mean emergence time (days) and seedling vigor index of rice.

to wheat diminished with increasing decomposition period and as a result, the residues decomposed for four weeks were less toxic than the undecomposed residues. This could be explained by the fact that allelopathic potential may vary in in different weed species. Abbas et al. (2014) identified chlorogenic acid, ferulic acid and m-coumaric acid in *Conyza stricta;* m-coumaric acid, p coumaric acid and vanilic acid in *Echinocloa crus-galli*; caffeic acid, chlorogenic acid, m-coumaric acid and p-coumaric acid in *Polygonum barbatum.* The presence of significantly higher amounts of phenolics (Figure 1 and Table 3) may be the reason for a greater effect of *A. philoxeroides* than *A. sessilis* on rice emergence and seedling traits. The results are supported by Paria and Mukherjee (1981), who recorded complete inhibition of mustard and rice seed germination and seedling growth with leaf extract of *A. philoxeroides.*

Thus, based on the present study, it could be concluded that phytotoxic phenolics in residues of *A. philoxeroides* and *A. sessilis* affect the emergence and growth of rice seedlings.

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