

Allelopathic potential of Malaysian invasive weed species on Weedy rice (*Oryza sativa* f. *spontanea* Roshev)

Mst. Motmainna¹, Abdul Shukor B Juraimi^{1*}, Md. Kamal Uddin²,
Norhayu Binti Asib³, A. K. M. Mominul Islam⁴ and Mahmudul Hasan¹

Department of Crop Science, Universiti Putra Malaysia (UPM),
Serdang, Selangor, Malaysia

E. Mail: ashukur@upm.edu.my; motmainnamou4@gmail.com

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ABSTRACT

In laboratory bioassay, we studied the effects of methanolic extracts of 30-Malaysian invasive weed species (9 families) on the seeds survival rate and seedlings growth of Weedy rice (*Oryza sativa* f. *spontanea* Roshev). Five concentrations [6.25, 12.5, 25, 50, 100 (g L⁻¹)] of methanolic extracts were used and control was distilled water. The Weedy rice seeds survival rate and seedlings growth (radicle and hypocotyl length) of 7-day-old seedlings were reduced by the increasing concentrations of extracts than control. Probit analysis and the concentrations required for 50% inhibition (EC₅₀) showed that radicle growth was more suppressed than seeds survival rate and hypocotyl growth. Among the tested weed species, *Parthenium hysterophorus* L., *Cleome ruidosperma* DC. and *Borreria alata* (Aubl.) DC. proved strongly allelopathic and thus, could be used to develop eco-friendly herbicides.

Keywords: Allelopathy, *Borreria alata*, *Cleome ruidosperma*, eco-friendly, herbicidal potential, invasive weeds, methanolic extracts, *Oryza sativa* f. *spontanea*, *Parthenium hysterophorus*, weed management, Weedy rice.

INTRODUCTION

Invasive weed species are threat to the biodiversity. Several mechanism including life history, physiological nature and rapid genetic changes are responsible for the plant invasion (16). The allelopathy is potential mechanism behind the success of non-native invasive weeds by producing new chemicals (24,37). Invasive weed species secrete allelochemicals which may have negative effect on associated species.

Weedy rice (*Oryza sativa* f. *spontanea*) is most troublesome weed in rice fields (21) and reduces rice yields from 5-100 % depending on the infestation in many countries including Malaysia (6,10,22,45). Its first infestation was recorded in 1988 in Malaysia (24). It is also known as red rice (genus *Oryza*) which competes with cultivated rice and other crops. Weedy rice and cultivated rice possess similar characteristics and is most harmful in direct seeded rice (10).

Recently, allelopathy has received much attention for managing weeds. Allelopathic interactions can be used either directly or indirectly by using the allelochemicals based herbicides (13). Allelopathy is the positive or negative impact of one plant on the germination and development of associated plants (42,51). The plants

*Correspondence author, ²Department of Land Management, ³Department of Plant Protection, Universiti Putra Malaysia (UPM), Serdang, Selangor, Malaysia, ⁴Department of Agronomy, Bangladesh Agricultural University (BAU), Mymensingh-2202, Bangladesh.

release allelochemicals in environment through volatilization, leachate, root exudates and decompo-



Figure 1. Donor plant *Oryza sativa* f. *spontanea* Roshev

sing biomass (1,54). Allelochemicals have short half-life than synthetic herbicides and thus are considered safe for environmental toxicology (38). Yousaf *et al.* (56) reported that several allelopathic plants have herbicidal effects on weeds. Aslani *et al.* (4) reported that the application of *Tinospora tuberculata* extracts significantly inhibited the germination, hypocotyl and radicle length of weedy rice but also slightly inhibited the rice growth. Decomposed tissue extract of *Scirpus grossus* at higher concentrations inhibited seedling growth of Weedy rice (28).



Figure 2. Invasive weeds with highest herbicidal activity to weedy rice.

However, the studies on invasive weeds to identify their possible allelopathic effects are inadequate. In Malaysian agro-ecosystems, there are 100 invasive weed species (7). Hence, this study aimed to evaluate the herbicidal effects of selected invasive weed species on the growth and development of Weedy rice.

MATERIALS AND METHODS

Location of the experiment

The experiment was conducted during January to March 2019 in growth chamber, Department of Crop Science, Faculty of Agriculture, Universiti Putra Malaysia (3° 02' N, 101°42' E, 31 m elevation), Selangor, Malaysia.

Collection of plant materials: Whole plants of 30 invasive weed species [(broadleaves, sedges and grasses from 9- families (Table 1)] were collected during the vegetative stage from Universiti Putra Malaysia and Ladang Infoternak, Sungai Siput, Perak, Malaysia.

Seeds collection: Weedy rice seeds were collected from the rice field of Sekinchan, Kuala Selangor, Selangor, Malaysia. After collection, the seeds were cleaned, dried and stored at 4°C in refrigerator. To break cold dormancy, before sowing seeds were kept for 1 h each in sun and shade.

Test plant: Seeds of Weedy rice were used as test plant owing to its quick germination and high sensitivity to phytochemicals at lower concentration.

Extraction procedure: The collected weeds were washed carefully with running tap water to remove the dust particles and air dried for 3 weeks. Then each species was chopped and powdered by grinder. One-hundred g powder of each species was soaked in 1000 mL of 80 % aqueous methanol into a conical flask and paraffin was used to wrap the flask. The flask was shaken in an orbital shaker for 48 h at room temperature (24-26 °C). The solution was filtered through four layers of cheese cloth to remove debris and centrifuged for 1 h at 3,000 rpm then re-filtered using a 0.2- μ , 15-mm syringe filters (Phenex, Non-sterile, Luer/Slip, LT Resources, Malaysia). The collected supernatant was evaporated by rotary evaporator at 40 °C. The dried residue were weighed and converted to % as under:

$$\text{Extraction (\%)} = [\text{Extract weight (g)} / \text{powder weight (g)}] \times 100$$

Each stock extract was diluted with sterile distilled water to get 6.25, 12.5, 25, 50, 100 g L⁻¹ concentrations of extract for bioassay. All extracts were stored in the dark at 4 °C in refrigerator until used. The methanol extracts were prepared as per Aslani *et al.* (4).

Laboratory bioassays

Healthy and uniform seeds of Weedy rice were sterilized by immersing for 24 h in 0.2 % potassium nitrate (KNO₃) and then rinsed thrice with distilled water. Twenty uniform pre-germinated seeds of Weedy rice per sterilized Petri dish (90×15 mm) were sown equidistant on two layers of filter paper. Each Petri dish was moistened with 10 mL extracts (6.25, 12.5, 25, 50 and 100 g L⁻¹) as per treatments and distilled water was used as control. The treatments were replicated 5- times in completely randomized design. The Petri dishes were kept in growth chamber (fluorescent light (8500 lux), 12h/12h (day/night cycle), temp: 30/20°C (day/night) and Relative humidity: 30 to 50 %). The lids of the Petri dishes were not sealed to allow gas exchange and to avoid the anaerobic condition. The petri plates were incubated until 1 mm long radicle emerged from the seed coat. Survival rate (%), radicles and hypocotyls length were measured after 7 days. The hypocotyl and radicle length of Weedy rice were photographed and measured using Image J software (35) and the inhibitory effects of selected 30-invasive weed species on weedy rice radicles and hypocotyls lengths were measured as under (4):

$$I=100 (C-A)/C$$

Where, I: Inhibition (%), C: radicles and hypocotyls lengths in control and A: radicles and hypocotyls lengths in methanol extracts.

Table 1. List of 30- invasive weeds used in this study

No.	Botanical name	Family	Crop	Yield reduction (%)	References
Broadleaf weeds					
1	<i>Amaranthus lividus</i> L.	Amaranthaceae	Cucumber	10 %	9
2	<i>Asystasia gangetica</i> L.	Acanthaceae	Oil palm	25 %	3
3	<i>Borreria alata</i> (Aubl.) DC.	Asteraceae	Maize	70 to 97 %	8
4	<i>Cleome ruidosperma</i> DC.	Cleomaceae	Sugarcane	15 % to 55 %	20
5	<i>Croton hirtus</i> L'Her.	Euphorbiaceae	Cassava	90 %	17
6	<i>Euphorbia hirta</i> L.	Euphorbiaceae	Field crops	4-85 %	53
7	<i>Hyptis capitata</i> Jacq.	Lamiaceae	Maize	60-81 %	23
8	<i>Lindernia crustacea</i> (L.) F.Muell.	Linderniaceae	Field crops	51 %	27
9	<i>Parthenium hysterophorus</i> L.	Asteraceae	Maize	21 to 50 %	48
10	<i>Xanthium indicum</i> DC.	Asteraceae	Cotton	6 to 27 %	47
Sedge weeds					
11	<i>Cyperus difformis</i> L.	Cyperaceae	Rice	12–50 %	40
12	<i>Cyperus digitatus</i> Roxb.	Cyperaceae	Rice	86% to 93 %	52
13	<i>Cyperus esculentus</i> L.	Cyperaceae	Rice	41 %	29
14	<i>Cyperus pilosus</i> Vahl	Cyperaceae	Rice	50 to 91 %	52
15	<i>Fimbristylis globulosa</i> (Retz.) Kunth	Cyperaceae	Rice	25 %	34
16	<i>Fimbristylis miliaceae</i> (L.) Vahl	Cyperaceae	Rice	44 to 96 %	34
17	<i>Rhynchospora corymbosa</i> (L.) Britton	Cyperaceae	Rice	28–74 %	46
18	<i>Scirpus grossus</i> L.f.	Cyperaceae	Rice	33 %	42
19	<i>Scirpus mucronatus</i> L.	Cyperaceae	Rice	10 to 35 %	42
20	<i>Scleria sumatrensis</i> Retz.	Cyperaceae	Rice	15 to 23 %	12
Grass weeds					
21	<i>Brachiaria mutica</i> (Forssk.) Stapf	Poaceae	Sugarcane	65.3 %	50
22	<i>Digitaria ciliaris</i> (Retz.) Koeler	Poaceae	Corn	99 %	27
23	<i>Ischaemum rugosum</i> Salisb.	Poaceae	Rice	50 to 60 %.	42
24	<i>Leersia hexandra</i> Sw.	Poaceae	Rice	30-40 %	2
25	<i>Leptochloa chinensis</i> (L.) Ness	Poaceae	Rice	10-35 %	19
26	<i>Ottochloa nodosa</i> (Kunth) Dandy	Poaceae	Oil palm	6 to 20 %	49
27	<i>Panicum repens</i> L.	Poaceae	Sugarcane	50 %	43
28	<i>Paspalum conjugatum</i> P.J. Bergius	Poaceae	Oil palm	6 to 20 %	49
29	<i>Paspalum distichum</i> L.	Poaceae	Rice	80 %	44
30	<i>Parapholis incurve</i> L.	Poaceae	Rice	30 to 40 %	41

Statistical analysis

A two-way analysis of variance (ANOVA) was carried out to determine any significant difference between each treatment and the control, the differences among the treatment means were grouped using the Tukey test at 0.05 probability level. The software SAS (statistical analysis system) (version 9.4) was used to conduct the analysis. EC_{s50} , EC_{r50} , and EC_{h50} are the effective doses which inhibited 50% of seeds germination, radicle and hypocotyl length respectively. Probit analysis based on inhibition (%) of survival rate, radicle and hypocotyl length was used to measure the EC_{s50} , EC_{r50} , and EC_{h50} . The most active extracts Rank (Re) was calculated using the equation given below (4):

$$\text{Rank (Re)} = EC_{s50n} (\text{Survival rate}) + EC_{r50n} (\text{Radicle}) + EC_{h50n} (\text{Hypocotyl})$$

The extracts with the lowest Re values were the most phytotoxic.

RESULTS AND DISCUSSION

Seeds survival rate of Weedy rice

The methanol extracts of 30 invasive weed species significantly inhibited the survival rate of Weedy rice (Table 2). The inhibitory effect of *P. hysterophorus*, *C. rutidosperma* and *B. alata* extracts were significantly higher than other invasive weed species (Figure 3). The lowest survival rate of weedy rice was at the maximum concentration of extract (100 g L^{-1}) and the highest survival rate was in control (distilled water). The extracts concentrations were responsible to inhibit the survival rate of Weedy rice. The invasive weeds confirmed allelopathic potential with significant variation between themselves. The highest concentration (100 g L^{-1}) of *P. hysterophorus* and *C. rutidosperma* extracts prevented the survival rate of Weedy rice seed (100 % inhibition), while, *B. alata* caused 83 % inhibition (Table 3). While the lowest conc (6.25 g L^{-1}) of all extracts except *P. hysterophorus* did not inhibit the seed germination of Weedy rice. The maximum mean inhibition of Weedy rice seed survival rate caused by the extracts followed the order: *P. hysterophorus* (56.17 %) > *C. rutidosperma* (45.17 %) > *B. alata* (40.17 %) > *L. chinensis* (7.83 %). In contrast, the *C. pilosa* and *L. hexandra* extracts at 100 g L^{-1} caused only 35 % inhibition in seed germination of Weedy rice.

Experimental results showed that out of thirty invasive weed species *P. hysterophorus*, *C. rutidosperma* and *B. alata* strongly influenced germination ability of Weedy rice by more than 90%. *P. hysterophorus* and *C. rutidosperma* completely inhibited (100%) the germination at higher concentration. The extracts of *P. hysterophorus* residues were rich in allelochemicals and exhibited phytotoxicity to the crops (30). Ladhari *et al.* (32) reported that 11- α -acetylbrachy-carpone-22(23)-ene was the most phytotoxic compound of *Cleome arabica* could be used for controlling different weeds on crop. According to Azairak and Karaman (5), extracts effectiveness against seed germination was active only at high concentration and not at low concentrations.

Table 2. Analysis of Variance (ANOVA) of inhibition (%) of methanol extracts of 30- invasive weed species on weedy rice

Source	df	Germination		Hypocotyl length		Radicle length	
		F	p	F	p	F	p
Plant species	29	193.36	<.0001	190.92	<.0001	91.57	<.0001
Concentrations	5	3913.36	<.0001	6080.86	<.0001	3263.78	<.0001
Plant species x Concentrations	145	26.32	<.0001	18.49	<.0001	7.39	<.0001

Seedlings growth of Weedy rice

Hypocotyl length: The hypocotyl length inhibition of Weedy rice seeds varied significantly in their response to examine extracts (Table 2). All methanol extracts resulted in remarkable reduction in hypocotyl growth of Weedy rice and the degree of reduction increase as the extract concentration increase (Table 4). Highly significant difference was obtained by using methanol extracts of *P. hysterophorus*, *C. rutidosperma* and *B. alata* on the hypocotyl length of Weedy rice. Hypocotyl length of Weedy rice was most negatively affected by *P. hysterophorus* extracts, followed by *C. rutidosperma* and *B. alata* (Fig. 4). The inhibitory effects ranged between 4.53% (*C. hirtus*) to 33.90% (*P. hysterophorus*) at lowest concentration (6.25 g L⁻¹) and 47.05% (*P. conjugatum*) and 100% (*P. hysterophorus*) at highest concentration (100 g L⁻¹). By increasing the concentration to 100 g L⁻¹, extracts of *P. hysterophorus* and *C. rutidosperma* were completely inhibited hypocotyl length of Weedy rice. For each extract, shorter hypocotyl length was observed at higher concentration (100 g L⁻¹).

The highest concentration (100 g L⁻¹) of *P. hysterophorus* and *C. rutidosperma* extracts prevented the germination of Weedy rice seed (100 % inhibition), hence, there was no hypocotyl growth. But *B. alata* caused 90 % reduction (Table 4). On the other hand, growth inhibition by extracts at high concentration and stimulation at very low concentration could be due to hormesis (11). Hormesis is the stimulatory activity of any compound at low doses (15). Some plant hormones increase the hypocotyl and radicle lengths at lower doses, but were inhibitory at higher doses (15), however, these hormones could be affected by some allelochemicals.

Radicle length: The methanolic extracts of 30-Malaysian invasive weeds significantly influenced the radicle length of Weedy rice (Table 2). The highest concentration of *P. hysterophorus* (100 %), *C. rutidosperma* (100 %) and *B. alata* (94.35 %) methanol extracts significant decreased the radicle length of Weedy rice (Table 5). At lowest concentration (6.25 g L⁻¹), the inhibitory effects followed the order: 62.37 % (*P. hysterophorus*) > 51.61 % (*C. rutidosperma*) > 49.43 % (*B. alata*) > 0.25 % (*X. indicum*). The inhibition in radicle length was increased with the increased concentration of extracts. The methanolic extracts of invasive weeds species were most inhibitory to radicle length than hypocotyl length. At the highest concentration (100 g L⁻¹) the *P. hysterophorus* and *C. rutidosperma* methanolic extracts completely inhibited the hypocotyl and radicle lengths of Weedy rice seedlings. Because these both weeds at 100 g L⁻¹ concentration prevented the seeds survival rate of Weedy rice. However, the *S. mucronatus* extracts at the highest concentration (100 g L⁻¹) caused radicle length inhibition of only 55.55 %.

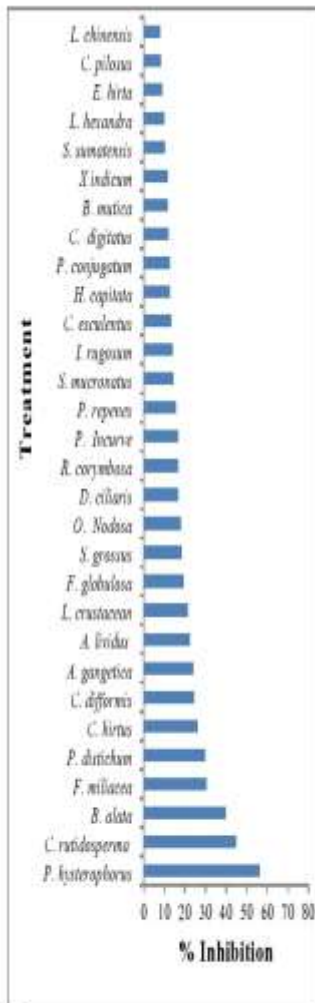


Figure 3. Germination inhibition (%) of Weedy rice

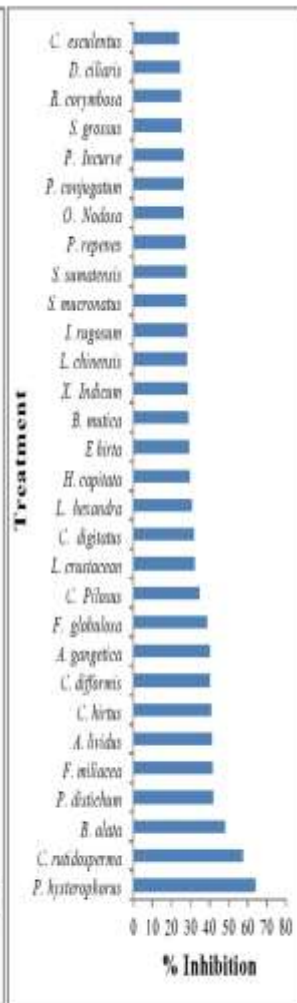


Figure 4. Hypocotyl length inhibition (%) of Weedy rice

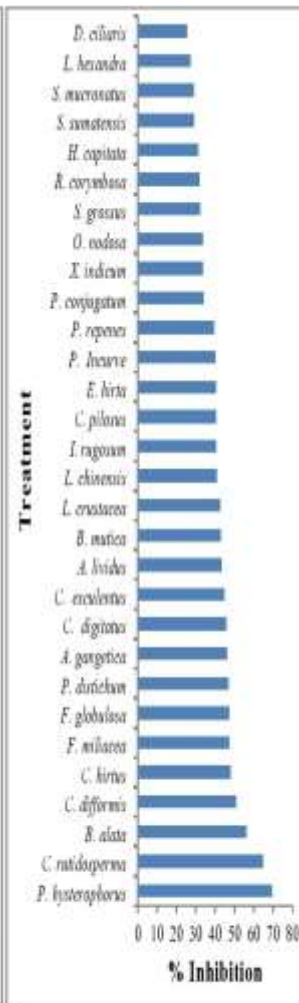


Figure 5. Radicle length inhibition (%) of Weedy rice

Table 3. Inhibitory effects of methanol extracts of 30- invasive weed species on survival rate inhibition (%) of Weedy rice

Sl. No.	Donor Weed	Inhibition (%) at various concentrations of methanol extracts				
		6.25g L ⁻¹	12.5 g L ⁻¹	25 g L ⁻¹	50 g L ⁻¹	100 g L ⁻¹
1	<i>P. hysterophorus</i> (B)	13.00a	51.00a	80.00a	93.00a	100.00a
2	<i>C. rutidosperma</i> (B)	4.00b	26.00b	56.00b	85.00ab	100.00a
3	<i>B. alata</i> (B)	3.00bc	19.00bc	49.00b	77.00bc	93.00ab
4	<i>F. miliacea</i> (S)	0.00c	14.00cd	36.00c	54.00de	77.00cd
5	<i>P. distichum</i> (G)	1.00bc	10.00cde	24.00de	62.00cd	80.00bcd
6	<i>C. hirtus</i> (B)	0.00c	7.00def	25.00cde	41.00ef	79.00bcd
7	<i>C. difformis</i> (S)	0.00c	9.00def	25.00cde	44.00ef	67.00de
8	<i>A. gangetica</i> (B)	0.00c	1.00ef	11.00f-j	45.00ef	86.00abc
9	<i>A. lividus</i> (B)	0.00c	9.00def	12.00f-j	32.00f-j	77.00cd
10	<i>L. crustacean</i> (B)	0.00c	8.00def	26.00cd	41.00ef	53.00e-i
11	<i>F. globulosa</i> (S)	0.00c	4.00ef	17.00d-h	35.00fgh	60.00ef
12	<i>S. grossus</i> (S)	0.00c	3.00ef	21.00def	37.00fg	48.00f-k
13	<i>O. nodosa</i> (G)	0.00c	4.00ef	14.00e-i	32.00f-j	58.00efg
14	<i>D. ciliaris</i> (G)	1.00bc	8.00def	12.00f-j	19.00i-m	60.00ef
15	<i>R. corymbosa</i> (S)	0.00c	5.00def	18.00d-g	34.00f-i	43.00g-k
16	<i>P. incurve</i> (G)	0.00c	3.00ef	10.00f-j	31.00f-k	55.00e-h
17	<i>P. repenes</i> (G)	0.00c	5.00def	11.00f-j	23.00g-l	54.00e-i
18	<i>S. mucronatus</i> (S)	0.00c	4.00ef	12.00f-j	24.00g-l	46.00f-k
19	<i>I. rugosum</i> (G)	0.00c	2.00ef	5.00ij	31.00f-k	46.00f-k
20	<i>C. esculentus</i> (S)	0.00c	1.00ef	6.00hij	23.00g-l	50.00f-k
21	<i>H. capitata</i> (B)	0.00c	6.00def	9.00g-j	22.00g-l	39.00ijk
22	<i>P. conjugatum</i> (G)	0.00c	4.00ef	9.00g-j	12.00lm	51.00f-j
23	<i>C. digitatus</i> (S)	0.00c	1.00ef	4.00ij	18.00j-m	49.00f-k
24	<i>B. mutica</i> (G)	0.00c	0.00f	6.00hij	16.00klm	47.00f-k
25	<i>X. indicum</i> (B)	0.00c	2.00ef	9.00g-j	17.00klm	41.00h-k
26	<i>S. sumatensis</i> (S)	0.00c	0.00ef	5.00ij	20.00h-m	37.00jk
27	<i>L. hexandra</i> (G)	0.00c	2.00ef	5.00ij	17.00j-m	35.00k
28	<i>E. hirta</i> (B)	0.00c	1.00ef	4.00ij	9.00lm	40.00h-k
29	<i>C. pilosus</i> (S)	0.00c	1.00ef	2.00j	11.00lm	35.00k
30	<i>L. chinensis</i> (G)	0.00c	2.00ef	3.00ij	6.00m	36.00jk
	Mean inhibition	0.73e	7.07d	17.53c	33.70b	58.07a

Data are expressed as mean inhibition. Means with same letters in the column for each concentration of invasive weed extract is not significantly different at $p < 0.05$. A value with same letter in the row for concentrations mean inhibition is not significantly different. Here,

B: Broadleaf weed, G: Grass weed, S: Sedge weeds. 6.25: 0.625%, 12.5: 1.25%, 25: 2.5%, 50: 5.0%, 100: 10.0%

Table 4. Inhibitory effects of methanol extracts of 30-invasive weed species on hypocotyl length inhibition (%) of Weedy rice

Sl. No.	Donor Weed	Inhibition (%) at various concentrations of methanol extracts				
		6.25 g L ⁻¹	12.5 g L ⁻¹	25 g L ⁻¹	50 g L ⁻¹	100 g L ⁻¹
1	<i>P. hysterophorus</i> (B)	33.90a	69.63a	84.57a	95.08a	100a
2	<i>C. rutidosperma</i> (B)	27.55ab	53.28b	80.11a	84.58ab	100a
3	<i>B. alata</i> (B)	18.64bcd	43.77c	58.62b	76.71bc	90.59b
4	<i>P. distichum</i> (G)	19.60bc	39.55cd	53.99b	60.69de	77.18c
5	<i>F. miliacea</i> (S)	19.08bc	29.26e-h	51.42bc	68.44cd	80.02c
6	<i>A. lividus</i> (B)	17.74b-e	32.04de	53.78b	62.93de	81.07c
7	<i>C. hirtus</i> (B)	4.53g	39.40cd	54.70b	64.66cde	81.55c
8	<i>C. difformis</i> (S)	16.69b-f	22.39g-k	55.76b	67.97cd	78.06c
9	<i>A. gangetica</i> (B)	15.57b-g	31.68def	40.14d	71.70bcd	81.57c
10	<i>F. globulosa</i> (S)	17.67b-e	26.80e-j	40.67cd	69.22cd	76.95c
11	<i>C. pilosus</i> (S)	8.07c-g	20.57i-l	40.44d	61.86de	77.53c
12	<i>L. crustacean</i> (B)	6.68d-g	30.30efg	41.17cd	54.27ef	59.79d-g
13	<i>C. digitatus</i> (S)	11.01c-g	27.24e-j	34.94def	53.74ef	64.11d
14	<i>L. hexandra</i> (G)	17.00b-f	28.27e-i	36.89def	44.75fgh	55.70ghi
15	<i>H. capitata</i> (B)	17.39b-e	21.17h-l	32.38d-g	42.50fgh	62.92de
16	<i>E. hirta</i> (B)	5.05fg	19.67jkl	38.52de	52.39efg	58.70d-g
17	<i>B. mutica</i> (G)	10.60c-g	23.09f-l	38.29de	41.87fgh	58.95d-g
18	<i>X. indicum</i> (B)	12.87c-g	20.28i-l	33.92def	41.16fgh	62.88def
19	<i>L. chinensis</i> (G)	17.34b-e	21.58h-l	32.74d-g	45.03fgh	52.23hij
20	<i>I. rugosum</i> (G)	9.14c-g	18.79jkl	36.62def	46.04fgh	57.47e-i
21	<i>S. mucronatus</i> (S)	10.61c-g	21.60h-l	38.47de	40.31gh	54.72ghi
22	<i>S. sumatensis</i> (S)	18.29bcd	21.23h-l	27.22fg	44.13fgh	54.69ghi
23	<i>P. repenes</i> (G)	12.45c-g	19.48jkl	35.03def	39.10h	57.39f-i
24	<i>O. nodosa</i> (G)	11.14c-g	19.09jkl	28.09efg	41.54fgh	57.71e-h
25	<i>P. conjugatum</i> (G)	13.89c-g	21.44h-l	36.41def	37.95h	47.05j
26	<i>P. incurve</i> (G)	6.57d-g	20.79h-l	30.94d-g	42.45fgh	55.91ghi
27	<i>S. grossus</i> (S)	16.52b-g	24.72e-j	28.54efg	34.12h	47.79j
28	<i>R. corymbosa</i> (S)	8.34c-g	20.37i-l	28.20efg	36.44h	56.05ghi
29	<i>D. ciliaris</i> (G)	11.06c-g	17.16kl	27.21fg	39.84gh	52.16ij
30	<i>C. esculentus</i> (S)	5.77efg	14.98l	22.86g	42.54fgh	56.15ghi
	Mean inhibition	14.03e	27.32d	41.42c	53.45b	66.56a

Data are expressed as mean inhibition. Means with same letters in the column for each concentration of invasive weed extract is not significantly different at $p < 0.05$. A value with same letter in the row for concentrations mean inhibition is not significantly different. Here,

B: Broadleaf weed, G: Grass weed, S: Sedge weeds. 6.25: 0.625%, 12.5: 1.25%, 25: 2.5 %, 50: 5.0%, 100: 10.0% .

Table 5. Inhibitory effects of methanol extracts of thirty invasive weed species on radicle length inhibition (%) of Weedy rice

Sl. No.	Donor Weed	Inhibition (%) at various concentrations of methanol extracts				
		6.25 g L ⁻¹	12.5 g L ⁻¹	25 g L ⁻¹	50 g L ⁻¹	100 g L ⁻¹
1	<i>P. hysterophorus</i> (B)	62.37a	71.84a	88.76a	92.28a	100.00a
2	<i>C. rudispermata</i> (B)	51.61ab	67.09ab	79.62a	88.30a	100.00a
3	<i>B. alata</i> (B)	49.43abc	52.51bcd	56.24bc	83.89ab	94.35ab
4	<i>C. difformis</i> (S)	35.00b-f	50.63bcd	61.08b	72.68bc	84.81bc
5	<i>C. hirtus</i> (B)	40.15bcd	53.45abc	56.95b	64.61c-f	71.21d-g
6	<i>F. miliacea</i> (S)	28.79c-h	46.48c-g	55.16bcd	68.73cde	83.86c
7	<i>F. globulosa</i> (S)	26.27d-i	51.79bcd	55.63bcd	71.60c	76.97cd
8	<i>P. distichum</i> (G)	28.85c-g	47.85cde	55.59bcd	63.12c-g	85.40bc
9	<i>A. gangetica</i> (B)	37.09b-e	46.46c-g	52.51b-e	64.00c-g	75.15cde
10	<i>C. digitatus</i> (S)	27.29d-h	46.69c-g	56.04bcd	64.84c-f	78.03cd
11	<i>C. esculentus</i> (S)	15.95e-j	49.68b-e	57.79b	67.98cde	76.34cd
12	<i>A. lividus</i> (B)	25.36d-i	39.10cd-j	57.51b	64.48c-g	72.51def
13	<i>B. mutica</i> (G)	19.72d-j	47.41c-f	53.73bcd	64.20c-g	70.90d-g
14	<i>L. crustacea</i> (B)	26.97d-h	48.95b-e	54.16bcd	58.54e-j	65.10e-i
15	<i>L. chinensis</i> (G)	18.61d-j	41.30c-i	44.08c-f	61.62c-i	78.34cd
16	<i>I. rugosum</i> (G)	10.65g-c	26.35h-k	56.36bc	71.31cd	77.18cd
17	<i>C. pilosus</i> (S)	12.81g-j	40.83c-i	56.27bc	59.79d-i	71.48d-g
18	<i>E. hirta</i> (B)	26.40d-i	29.31f-k	54.72bcd	63.36c-i	68.06d-h
19	<i>P. incurve</i> (G)	8.29g-j	42.82c-h	54.68bcd	62.90c-h	70.46d-g
20	<i>P. repenes</i> (G)	11.40g-j	34.99c-k	55.04bcd	62.39c-h	70.86d-g
21	<i>P. conjugatum</i> (G)	13.28g-j	28.46g-k	38.60fg	54.92f-j	68.42d-g
22	<i>X. indicum</i> (B)	0.251j	31.46e-k	52.46b-e	55.98f-j	61.75ghi
23	<i>O. nodosa</i> (G)	8.53g-j	34.30d-k	40.97efg	54.92f-j	62.90f-i
24	<i>S. grossus</i> (S)	13.34f-j	31.30e-k	40.80efg	55.42f-j	64.57fi
25	<i>R. corymbosa</i> (S)	4.72ij	26.48h-k	43.81def	50.03g-k	62.55f-i
26	<i>H. capitata</i> (B)	13.23g-j	21.10jkl	34.22fgh	54.19f-k	63.15f-i
27	<i>S. sumatensis</i> (S)	7.11hij	19.35kl	35.27fgh	50.95ijk	59.71hi
28	<i>S. mucronatus</i> (S)	8.46g-j	20.04kl	36.75fg	51.49h-k	55.55i
29	<i>L. hexandra</i> (G)	8.17g-j	24.14i-l	23.71h	43.22k	63.82f-i
30	<i>D. ciliaris</i> (G)	2.89j	5.82l	30.77gh	48.01jk	65.33e-i
	Mean inhibition	21.43e	39.27d	51.31c	63.06b	73.29a

Data are expressed as mean inhibition. Means with same letters in the column for each concentration of invasive weed extract is not significantly different at $p < 0.05$. A value with same letter in the row for concentrations mean inhibition is not significantly different. Here, B: Broadleaf weed, G: Grass weed, S: Sedge weeds. 6.25: 0.625%, 12.5: 1.25%, 25: 2.5 %, 50: 5.0%, 100: 10.0%

The radicle length of Weedy rice was inhibited more than 90% at the concentration of 50 g L⁻¹. At 100 g L⁻¹ concentration, out of thirty invasive weed species *P. hysterophorus* and *C. rutidosperma* showed complete inhabitation while *B. alata* exhibited more than 90% inhibition of radicle length of Weedy rice (Figure 5). The results confirmed that radicle length inhibition was more significant than hypocotyl length inhibition of Weedy rice. Generally, radicle is more sensitive compare to hypocotyl because as a first organ radicle absorb phytotoxic compounds from extract concentration and also these phytotoxic compounds exhibit higher permeability into radicle tissue compare to hypocotyl (25). The stronger harmful effects of invasive weed species extract on radicle growth could be

Table 6. Comparison of allelopathic activity of 30 invasive weed species extract

Sl. No.	Invasive weed extract	EC _{s50}	EC _{h50}	EC _{r50}	Allelopathic activity Rank
		Values in g L ⁻¹			
1	<i>P. hysterophorus</i> (B)	13.47	8.72	4.43	I
2	<i>C. rutidosperma</i> (B)	21.88	11.67	6.38	II
3	<i>B. alata</i> (B)	27.55	17.90	7.94	III
4	<i>P. distichum</i> (G)	43.05	24.80	17.62	I V
5	<i>F. miliaceae</i> (S)	42.97	25.35	17.23	V
6	<i>C. hirtus</i> (B)	51.93	26.47	12.70	VI
7	<i>A. gangetica</i> (B)	52.92	27.00	17.06	VII
8	<i>C. difformis</i> (S)	58.48	27.13	13.20	VIII
9	<i>A. lividus</i> (B)	62.84	25.42	22.48	IX
10	<i>F. globulosa</i> (S)	74.23	29.59	16.96	X
11	<i>P. incurve</i> (G)	85.62	70.06	28.17	XI
12	<i>L. crustacea</i> (B)	74.98	46.76	21.81	XII
13	<i>C. digitatus</i> (S)	103.97	47.05	18.62	XIII
14	<i>I. rugosum</i> (G)	100.03	61.25	27.03	XIV
15	<i>B. mutica</i> (G)	107.82	62.20	22.96	XV
16	<i>C. esculentus</i> (S)	98.60	74.74	20.15	XVI
17	<i>O. nodosa</i> (G)	80.01	72.26	42.85	XVII
18	<i>P. repens</i> (G)	96.33	71.50	29.37	XVIII
19	<i>C. pilosus</i> (S)	146.44	35.49	26.36	XIX
20	<i>E. hirta</i> (B)	135.39	52.99	25.35	XX
21	<i>R. corymbosa</i> (S)	104.32	80.80	45.52	XXI
22	<i>X. indicum</i> (B)	132.58	59.61	40.00	XXII
23	<i>D. ciliaris</i> (G)	93.84	89.10	55.97	XXIII
24	<i>S. mucronatus</i> (S)	111.66	71.50	58.43	XXIV
25	<i>S. sumatrensis</i> (S)	128.50	71.23	54.69	XXV
26	<i>H. capitata</i> (B)	145.40	61.20	48.76	XXVI
27	<i>P. conjugatum</i> (G)	115.32	106.46	40.24	XXVII
28	<i>L. chinensis</i> (G)	162.79	80.39	26.60	XXVIII
29	<i>S. grossus</i> (S)	87.51	145.12	40.68	XXIX
30	<i>L. hexandra</i> (G)	153.45	66.24	60.87	XXX
Rank (Re)		2713.88	1650	874.83	

EC_{s50}, EC_{h50} and EC_{r50} are the concentration of extracts that inhibits 50 % of survival rate, hypocotyl and radicle respectively.

described by the higher absorption of allelopathic substances through radicle in close contact with the extracts. Allelochemicals reduce radicle development by disturbing genes which are responsible for cellular characterization of ground tissue and endoderm (12). On the other hand many researchers found low mitotic divisions were responsible for higher root inhibition (26,31,39).

Allelopathic activity of 30 invasive weed species extracts

The half effective concentrations of each tested extract for Weedy rice have been given in Table 6. The extracts derived from different invasive weeds exhibited variable inhibitory effects on the seed survival rate and seedling growth of Weedy rice. The differences were evident from the rank values of extracts. *P. hysterophorus*, *C. rutidosperma* and *B. alata* showed highest inhibitory effects. Weedy rice proved most sensitive to the methanol extract of *P. hysterophorus*, *C. rutidosperma* and *B. alata*. Thereafter, the rank values of *L. hexandra* are 10 times more than *P. hysterophorus*. From 30 invasive weed species *P. hysterophorus* had the lowest EC₅₀, indicating *P. hysterophorus* had the highest allelopathic potential.

The comparison of rank values (Re) of all extracts on survival rate, hypocotyl and radicle growth indicated that radicles were more sensitive than other growth parameters. The tested extracts significantly inhibited the radicle development of Weedy rice. The Weedy rice calculated value of EC_{r50} (Radicle length) was 4.43 g L⁻¹ for *P. hysterophorus* extract, while, the EC_{h50} (Hypocotyl length) value was 8.72 g L⁻¹. The inhibitory effects of extracts indicate that the absorption of allelochemicals through radicles was higher than the hypocotyl. Similar result was also reported by Aslani *et al.* (4) and found that the EC_{r50} value was 19.80 g L⁻¹ while the EC_{h50} value was 49.10 g L⁻¹ for rice seeds when treated with methanol extract of *Tinospora tuberculata*. Stronger allelopathic effects of extracts on radicle have been reported by Meksawat and pornprom (33). Therefore, the herbicidal potential of extracts can be evaluated through root index. Theranking for most sensitive extracts according to Re value was *P. hysterophorus* < *C. rutidosperma* < *B. alata*. Therefore, Weedy rice is most sensitive to *P. hysterophorus* and *C. rutidosperma* extract than other extracts for all measured parameters.

The results confirmed the allelopathic effects of 30-invasive weed species on the survival rate and seedlings growth of Weedy rice. The present findings are similar to Valcheva *et al.* (55) who reported that extracts of 10 invasive weed species applied to *Lactuca sativa* and showed higher suppressive effects on germination and initial growth. Germination and initial development of *E. crus-galli* was suppressed effectively by the application of methanol extracts of *T. tuberculata* (4). Pannacci *et al.* (39) found that mugwort extract inhibited the germination, hypocotyl and radicle lengths of *Sinapsis alba* and may be considered as potent inhibitor of germination and growth of *Lolium multiflorum*. Belchim Crop Protection USA, has launched 'Beloukha herbicide', sunflower bio-based, non-selective, contact, broad-spectrum, foliar-applied herbicide that destroys the cell membranes of plant epidermis causing rapid tissue dehydration of both annual and

perennial broadleaf and grass weeds (14). It contains 98% pelargonic acid a naturally occurring allelochemicals present in sunflower (14).

CONCLUSIONS

All 30-test Malaysian invasive weed species allelopathically inhibited the seeds germination and seedlings growth of Weedy rice (*Oryza sativa* f. *spontanea*). The allelopathic effects of these weed species varied and depended on the extract concentrations. The *P. hysterophorus*, *C. rutidosperma* and *B. alata* weeds were most inhibitory to survival rate and seedlings growth of Weedy rice. Hence, these weeds species chemical components needs to be isolated and identified to develop natural products based eco-friendly bioherbicide to control Weedy rice in sustainable agriculture.

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REFERENCES

1. Albuquerque, M.B., Santos, R.C., Lima, L.M., Melo-Filho, P.D.A., Nogueira, R.J.M.C. and Câmara, C.A.G. (2010). Allelopathy, an alternative tool to improve cropping systems. *Agronomy for Sustainable Development* **31**: 379-395.
2. Al Mamun, M., Shultana, R., Rana, M. and Mridha, A.J. (2013). Economic threshold density of weed species for direct seeded rice. *Asian Journal of Agriculture and Rural Development* **3**: 523-531.
3. Asbur, Y., Purwaningrum, Y. and Ariyanti, M. (2018). Growth and nutrient balance of *Asystasia gangetica* (L.) as cover crop for mature oil palm (*Elaeis guineensis* Jacq.) plantations. *Chilean Journal of Agricultural Research* **78**: 486-494.
4. Aslani, F., Juraimi, A.S., Ahmad-Hamdani, M.S., Omar, D., Alam, M.A., Hashemi, F.S.G. and Uddin M.K. (2014). Allelopathic effects of methanol extracts from *Tinospora tuberculata* on selected crops and rice weeds. *Acta Agriculturae Scandinavica, Section B - Soil & Plant Science* **64**: 165-177.
5. Azirak, S. and Karaman, S. (2008). Allelopathic effect of some essential oils and components on germination of weed species. *Acta Agriculturae Scandinavica, Section B - Soil & Plant Science* **58**: 88-92.
6. Azmi, B.M., Juraimi, A.S. and Najib, M.M.Y. (2007). Critical period of weedy rice control in direct seeded rice. *Journal of Tropical Agriculture and Food Science* **35**: 319-332.
7. Bakar, B.H. (2004). Invasive weed species in Malaysian agro-ecosystems: Species, impacts and management. *Malaysian Journal of Sciences* **23**: 1-42.
8. Barbosa, P.I., Lima, P.S., de Oliveira, O.F. and de Sousa, R.P. (2008). Planting times of cowpea intercropped with corn for the weed control. *Revista Caatinga* **21**: 113-119.
9. Berry, A.D., Stall, W.M., Rathinasabapathi, B., Macdonald, G.E. and Charudattan, R. (2006). Smooth pigweed (*Amaranthus hybridus* L.) and livid amaranth (*Amaranthus lividus*) interference with cucumber (*Cucumis sativus*). *Weed Technology* **20**: 227-231.
10. Busi, R., Nguyen, N.K., Chauhan, B.S., Vidotto, F., Tabacchi, M. and Powles, S.B. (2017). Can herbicide safeners allow selective control of weedy rice in rice crop? *Pest Management Science* **73**: 71-77.
11. Calabrese, E.J. and Blain, R.B. (2009). Hormesis and plant biology. *Environmental Pollution* **157**: 42-48.
12. Chandrasena, J.P.N.R. (1988). Floristic composition and abundance of weeds in rice-field in four Wet Zone districts of Sri Lanka. *International Journal of Pest Management* **34**: 278-287.
13. Cheng, F. and Cheng, Z. (2015). Research progress on the use of plant allelopathy in agriculture and the physiological and ecological mechanisms of allelopathy. *Frontiers in Plant Science* **6**: 1020.

14. Ciriminna, R., Fidalgo, A., Ilharco, L.M. and Pagliaro, M. (2019). Herbicides based on pelargonic acid: Herbicides of the bioeconomy. *Biofuels, Bioproducts and Biorefining* **13**: 1476-1482.
15. Duke, S.O., Cedergreen, N., Velini, E.D. and Belz, R.G. (2006). Hormesis: is it an important factor in herbicide use and allelopathy? *Outlooks on Pest Management* **17**: 29-33.
16. Ehrenfeld, J.G., Kourtev, P. and Huang, W. (2001). Changes in soil functions following invasions of exotic understory plants in deciduous forests. *Ecological Applications* **11**: 1287-1300.
17. Ekeleme, F., Atser, G., Dixon, A., Hauser, S., Chikoye, D., Olorunmaiye, P.M. and Lagoke, S. T. O. (2019). Assessment of weeds of cassava and farmers management practices in Nigeria. *Tropicicultura* **37**: 1-12.
18. Franco, D.M., Silva, E.M., Saldanha, L.L., Adachi, S.A., Schley, T.R., Rodrigues, T.M., De Almeida, L.F.R. (2015). Flavonoids modify root growth and modulate expression of SHORT-ROOT and HD-ZIP III. *Journal of Plant Physiology* **188**: 89-95.
19. Gao, P., Zhang, Z., Shen, J., Mao, Y., Wei, S., Wei, J. and Qiang, S. (2020). Weed seed bank dynamics responses to long-term chemical control in rice-wheat cropping system. *Pest Management Science* **76**: 1993-2003.
20. Ghosh, P., Chatterjee, S., Das, P., Karmakar, S. and Mahapatra, S. (2019). Natural habitat, phytochemistry and pharmacological properties of a medicinal weed—*Cleome ruidosperma* DC. (Cleomaceae): A comprehensive review. *International Journal of Pharmaceutical Sciences and Research* **10**: 1605-1612.
21. Hakim, M.A., Juraimi, A.S., Ismail, M.R., Hanafi, M.M. and Selamat, A. (2010). Distribution of weed population in costal rice growing area of kedah in peninsular Malaysia. *Journal of Agronomy* **9**: 9-16.
22. He, Z.X., Jiang, X.Q., Ratnasekera, D., Grassi, F., Perara, U. and Lu, B.R. (2014). Seed mediated gene flow promotes genetic diversity of weedy rice within population: Implication of weed management. *Plos one* **9**: e112778.
23. Imoloame, E.O. and Omolaiye, J.O. (2017). Weed infestation, growth and yield of maize (*Zea mays* L.) as influenced by periods of weed interference. *Advance in Crop Science and Technology* **5**: 267-273.
24. Inderijt (2005). Soil Microorganisms: An important determinant of allelopathic activity. *Plant and Soil* **274**: 227-236
25. Islam, A.K.M.M., and Kato-Noguchi, H. (2013). Plant growth inhibitory activity of medicinal plant *Hyptis suaveolens*: Could allelopathy be a cause? *Emirates Journal of Food and Agriculture* **25**: 692-701
26. Islam, A.K.M.M., Ohno, O., Suenaga K. and Kato-Noguchi, H. (2014). Two novel phytotoxic substances from *Leucas aspera*. *Journal of Plant Physiology* **171**: 877-883.
27. Jabran, K. and Chauhan, B.S. (2015). Weed management in aerobic rice systems. *Crop Protection* **78**: 151-163.
28. Karthikeyan, P.G. and George, S. (2017). Allelopathic effects of greater club rush on rice and weedy rice. *Trends in Biosciences* **10**: 1099-1102
29. Keeley, P.E. (1987). Interference and interaction of purple and yellow nutsedges (*Cyperus rotundus* and *C. esculentus*) with crops. *Weed Technology* **1**: 74-81.
30. Khaliq, A., Aslam, F., Matloob, A., Javaid, A., Tanveer, A., Hussain, S. and Ihsan M.Z. (2016). Phytotoxic activity of parthenium against wheat and canola differ with plant parts and bioassays techniques. *Planta Daninha* **34**: 11-24.
31. Khan, M.S.I., Islam, A.K.M.M. and Kato-Noguchi, H. (2013). Evaluation of allelopathic activity of three mango (*Mangifera indica*) cultivars. *Asian Journal of Plant Sciences* **12**: 252-261.
32. Ladhari, A., Omezzine, F., Della-Greca, M., Zarrelli, A., Zuppolini, S. and Haouala, R. (2013). Phytotoxic activity of *Cleome arabica* L. and its principal discovered active compounds. *South African Journal of Botany* **88**: 341-351
33. Meksawat, S. and Pornprom, T. (2010). Allelopathic effects of itchgrass (*Rottboellia cochinchinensis*) on seed germination and plant growth. *Weed Biology and Management* **10**: 16-24.
34. Mesquita, M.L.R., Andrade, L.A.D. and Pereira, W.E. (2013). Floristic diversity of the soil weed seed bank in a rice-growing area of Brazil: *in-situ* and *ex-situ* evaluation. *Acta Botanica Brasilica* **27**: 465-471.
35. Mirmostafae, S., Azizi, M. and Fujii, Y. (2020). Study of allelopathic interactions of essential oils from medicinal and aromatic plants on seed germination and seedling growth of lettuce. *Agronomy Journal* **10**: 163.
36. Mispan, M.S., Bzoor, M., Mahmud, I., MD-Akhir, A.H. and Zulrushdi, A. (2019). Managing weedy rice (*Oryza sativa* L.) in Malaysia: Challenges and ways forward. *Journal of Research in Weed Science* **2**: 149-167.
37. Morikawa, C.I.O., Miyaura, R., Figueroa, M.D.L.T.Y., Salgado, E.L.R. and Fujii, Y. (2012). Screening of 170 Peruvian plant species for allelopathic activity using the sandwich method. *Weed Biology and Management* **12**: 1-11.

38. Motmianna, M., Juraimi A.S., Uddin M.K. Asib, N.B., Islam, A.K. M.M. and Hasan, M. (2021). Assessment of allelopathic compounds to develop new natural herbicides: A review. *Allelopathy Journal*:52: 21-40.
39. Pannacci, E., Pettorossi, D., Regni, L. and Tei, F. (2015). Allelopathic potential of mugwort (*Artemisia vulgaris* L.) to control the Italian ryegrass (*Lolium multiflorum* Lam.) in winter wheat. *Allelopathy Journal* **36**: 257-272.
40. Rabbani, N., Bajwa, R. and Javaid, A. (2011). Interference of five problematic weed species with rice growth and yield. *African Journal of Biotechnology* **10**: 1854-1862.
41. Rahman, M.T., Ahmed, S., Lipi, N.J., Rashid, M.H. and Hoque, M.I. (2014). Critical period of weed competition in transplant Aus rice cv. BRRI dhan27 under non-saline agro-ecosystem. *Bangladesh Agronomy Journal* **17**: 95-102.
42. Rao, A.N., Johnson, D.E., Sivaprasad, B., Ladha, J.K. and Mortimer, A.M. (2007). Weed management in direct-seeded rice. *Advances in Agronomy* **93**: 153-255.
43. Rao, D.A. and Padal, S.B. (2015). Weed species in sugarcane crop fields of Chodavaram mandal of Visakhapatnam district, Andhra Pradesh, India. *Journal of Plant & Agriculture Research* **1**: 1-5.
44. Ranjit, J.D. and Suwanketnikom, R. (2005). Response of weeds and yield of dry direct seeded rice to tillage and weed management. *Agriculture and Natural Resources* **39**: 165-173.
45. Rice, E.L. (1984). *Allelopathy*. Academic Press, Orlando, FL, USA. Pp. 424.
46. Rodenburg, J. and Johnson, D.E. (2009). Weed management in rice-based cropping systems in Africa. *Advances in Agronomy* **103**: 149-218.
47. Saeed, A., Hussain, A., Khan, M.I., Arif, M., Maqbool, M.M., Mehmood, H. and Elshikh, M.S. (2020). The influence of environmental factors on seed germination of *Xanthium strumarium* L.: Implications for management. *Plos one* **15**: e0241601.
48. Safdar, M.E., Tanveer, A., Khaliq, A. and Riaz, M.A. (2015). Yield losses in maize (*Zea mays*) infested with parthenium (*Parthenium hysterophorus* L.) weed. *Crop Protection* **70**: 77-82.
49. Samedani, B., Juraimi, A.S., Abdullah, S. A.S., Rafii, M.Y., Rahim, A.A. and Anwar, M. (2014). Effect of cover crops on weed community and oil palm yield. *International Journal of Agriculture and Biology* **16**: 23-31.
50. Singh, R., Sen, D., Singh, V.K., Rana, N.S. and Kumar, S. (2005). Effects of weed-management practices on spring-planted sugarcane. *Indian Journal of Agronomy* **50**: 236-238.
51. Southam, C.M. and Erlich J., (1943). Effects of extract of western red-cedar heartwood on certain wood-decaying fungi in culture. *Phytopathology* **33**: 517-524.
52. Suria, A.J., Juraimi, A.S., Rahman, M., Man, A.B. and Selamat, A. (2011). Efficacy and economics of different herbicides in aerobic rice system. *African Journal of Biotechnology* **10**:8007-8022.
53. Tanveer, A., Khaliq, A., Javaid, M.M., Chaudhry, M.N. and Awan, I. (2013). Implications of weeds of genus euphorbia for crop production: A review. *Planta Daninha* **31**:723-731.
54. Uddin, M.K., Shamsuzzaman, S.M., Lo, L.Q., Medom, M. and Hasan, M. (2017). Effects of salinity on growth, antioxidant contents and proximate compositions of sabah snakegrass (*Clinacanthus nutans* (Burm. F.) Landau). *Bangladesh Journal of Botany* **46**(1): 263-269.
55. Valcheva, E., Popov, V., Serafimov, P.M., Golubinova, I., Nikolov, B., Velcheva, I. and Petrova, S. (2017). Allelopathic effect of some weed species on germination and initial development of *Lactuca sativa*. *Proc.VIII International Scientific Agriculture Symposium, "Agrosym 2017"*, Jahorina, Bosnia and Herzegovina, pp. 170-175. Faculty of Agriculture, University of East Sarajevo, Bosnia- Herzegovina.
56. Yousaf, M., Shahzadi, H., Anjum, A., Zahoor, A.F., Khan, Z.I., Idrees, S. and Mubeen, Z. (2014). Constitutional composition and allelopathic potential of jaman (*Syzygium cumini*) leaves against canary grass and wheat. *Pakistan Journal of Weed Science* **20**: 323-334.