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Article

Allelopathic Effect of *Parthenium hysterophorus* on Germination and Growth of Some Important Crops and Weeds of Economic Importance

*Efeito Alelopático de **Parthenium hysterophorus** sobre a Germinação e o Crescimento de Algumas Culturas Relevantes e Plantas Daninhas de Importância Econômica*

HASSAN, G.[1,2*]
RASHID, H.U.[1]
AMIN, A.[1]
KHAN, I.A.[1]
SHEHZAD, N.[3]

ABSTRACT - *Parthenium hysterophorus* being a declared invasive weed worldwide is threatening the biodiversity of Pakistan. To study its allelopathic potential, laboratory and pots based studies were undertaken during July-August and October-November, 2010 in Weed Research Laboratory, Department of Weed Science, The University of Agriculture Peshawar, Khyber Pakhtunkhwa Pakistan. The experiments were conducted to investigate the allelopathic effect of parthenium on crops *Triticum aestivum*, *Cicer arietinum* and *Brassica campestris*, and weeds including *Avena fatua*, *Asphodelus tenuifolius* and *Lolium rigidum* The fresh leaves of *P. hysterophorus* were dried in shade and grinded. The desired quantity of powder was soaked for 16 hr. in the desired quantity of water to make the stock solution of the maximum concentration viz. 75 g L^{-1}. Five seeds of each species were placed in Petri dishes and in pots, extracts were applied when needed. Control (0 g L^{-1}) was also included for comparison. Both experiments were laid out as Factorial in completely randomized design (CRD) with four replications and two runs each. Since the statistical differences between the runs were non-significant the data were pooled before subjecting it to ANOVA and mean separation. The differences among the test species and the rates of parthenium extracts were different statistically ($P \leq 0.05$) for all the traits examined, while for the species x parthenium concentration interaction, the differences were only significant ($P \leq 0.05$) for plant height in the pot experiment. The results showed that with the increasing concentration of *P. hysterophorus*, all the parameters studied in the six test species were significantly decreased. Hence, the present study suggests that *P. hysterophorus* affects the agro-ecosystem and needs to be properly managed, moreover, its allelopathy on weeds is an encouraging finding for the weed managers for the sustainable management of weeds.

Keywords: parthenium, allelopathy, wheat.

*RESUMO - A losna-branca (**Parthenium hysterophorus**) é considerada uma planta invasora no mundo inteiro e está ameaçando a biodiversidade do Paquistão. Para estudar o potencial alelopático da espécie, foram realizados estudos em laboratório e vasos durante os meses de julho-agosto e outubro-novembro de 2010 no Laboratório de Pesquisa sobre Plantas Daninhas, Departamento de Plantas Daninhas, University of Agriculture Peshawar, Khyber Pakhtunkhwa, Paquistão. Os experimentos foram conduzidos para investigar o efeito alelopático da losna-branca nas culturas de **Triticum aestivum**, **Cicer arietinum** e **Brassica campestris** e de plantas daninhas, incluindo **Avena fatua**, **Asphodelus tenuifolius***

*** Corresponding author:**
<hassanpk_2000pk@yahoo.com>

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[1] Department of Weed Science, The University of Agriculture, Peshawar, Pakistan; [2] Department of Agriculture, Shaheed Benazir Bhutto University, Sheringal Dir Upper, Pakistan, [3] Department of Agricultural Sciences, University of Haripur, Khyber Pakhtunkhawa, Pakistan.

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*e **Lolium rigidum**. As folhas frescas de **P. hysterophorus** foram secas à sombra e trituradas. A quantidade desejada de pó foi embebida durante 16 horas na quantidade desejada de água para produzir a solução-estoque da concentração máxima (75 g L^{-1}). Cinco sementes de cada espécie foram colocadas em placas de Petri e em vasos, e os extratos foram aplicados quando necessário. Um grupo controle (0 g L^{-1}) também foi incluído para fins de comparação. Ambos os experimentos foram definidos como fatoriais, em um delineamento inteiramente casualizado (DCI) com quatro repetições e duas corridas experimentais cada. Como não houve diferenças estatísticas significativas entre as corridas experimentais, os dados foram agrupados antes de serem submetidos a ANOVA e separação de médias. As diferenças entre as espécies testadas e as doses de extratos de **P. hysterophorus** foram estatisticamente significativas ($P\leq0,05$) para todos os traços investigados. Já para a interação entre espécie x concentração de **P. hysterophorus**, as diferenças foram significativas ($P\leq0,05$) apenas para altura da planta no experimento em vaso. Os resultados mostraram que, com o aumento da concentração de **P. hysterophorus**, todos os parâmetros estudados nas seis espécies testadas tiveram redução significativa. Assim, o presente estudo sugere que **P. hysterophorus** afeta o agroecossistema e precisa ser manejada corretamente. Além disso, o efeito alelopático dessa espécie nas plantas daninhas é um resultado promissor para o manejo sustentável delas.*

Palavras-chave: parthenium, alelopatia, trigo.

INTRODUCTION

Parthenium weed, Carrot weed, Ragweed, White top or Congress grass (Family Asteraceae), is a cosmopolitan invasive weed. Its harms include threats to biodiversity, allergies, dermatitis and mutagenesis in humans and livestock and interference (competition and allelopathy) with field crops and rangelands (Patel, 2011 and references therein). It is distributed in all inhabited continents viz. Asia, Africa, Europe, Americas and Australia, under very diverse ecological conditions, and its recent record under as harsh climate as desert in United Arab Emirates (Mahmoud et al., 2015). The earliest record of parthenium in India is in 1951 in Poona, while in Pakistan it was reported in the 1980s in the Gujrat district (Rao, 1956; Razaq et al., 1988). However, it is native of Mexico and endemic to the American tropics. The weed has been spreading like wild fire in different countries. In Pakistan, it is infesting both cultivated land and wasteland (roadsides, railroads, water courses, canals, river banks, drains, orchards and construction sites) (Hassan and Amin, 2009; Khan et al., 2014). Allelopathy is a chemical warfare among the plants to keep other plants out of their neighborhood. Parthenium contains chemicals such as parthenin, hysterin, hymenin, and ambrosin. Because of these chemicals, mainly parthenin, it wins the war to capture space and keep its competitors out of that space (Batish et al., 1997a; Belz et al., 2007; Belz, 2008, 2016). Parthenin has been reported as a germination and radicle growth inhibitor in a variety of dicot and monocot plants. The allelochemicals released from plants may inhibit shoot/root growth and nutrient uptake, or they may attack a naturally occurring symbiotic relationship thereby destroying the plants' usable source of nutrients (Conn, 1980; Khan et al., 2005; Hassan, et al., 2008; Safdar et al., 2014). There have been previous reports of the inhibitory effects of *P. hysterophorus*, an invasive alien weed, on germination of many crops (Meirse and Singh, 1987; Maharjan et al., 2007; Acharya and Rahman, 1997).

Although an efficient and prompt solution for many weed problems exists through synthetic chemicals, the fate of herbicides still remains controversial as they have posed serious ecological and health hazards. Indiscriminate herbicide usage is driving agro-ecosystems towards dwindling species diversity and, in many situations, it is leading to herbicide resistance (Powels and Yu, 2001; Vila-Aiub et al., 2005; Storrie et al., 2014). Utilization of allelopathic properties of allelopathic plant species offers promising opportunities for sustainable weed management (Lorenzo et al., 2013).

Keeping in view the importance of the allelopathic potential of *P. hysterophorus*, two runs of each experiment were conducted under laboratory and pot conditions, respectively, with the following objectives: i) to investigate the allelopathic effect of parthenium on some crops and weeds viz *Triticum aestivum*, *Cicer arietinum*, *Brassica campestris*, *Avena fatua*, *Asphodelus tenuifolius* and *Phalaris minor*, ii) to quantify the allelopathic effect of parthenium on the growth and development of crops and weeds, and iii) to explore the possibility of parthenium extract as a potential bioherbicide.

MATERIALS AND METHODS

Experimental site and design

Laboratory and Pot experiments entitled "Allelopathic effect of *Parthenium hysterophorus* on germination and growth of some crops and weeds of Khyber Pakhtunkhwa Province Pakistan" were conducted at the Weed Research Laboratory, Department of Weed Science, University of Agriculture Peshawar, Pakistan (34.0150° N, 71.5805° E), in July-August and October-November, 2010. The factorial experiments were laid out in Completely Randomized Design (CRD) with four replications. The test species were three crops and three weeds, while four treatments with parthenium extract were applied at different concentrations.

Preparation of parthenium extracts

The parthenium plants were collected from the Swabi District of the Khyber Pakhtunkhwa Province, Pakistan, at pre-flowering stage, and then washed and dried in shade for about one month. The dried leaves were separated from stems and ground in the laboratory in a mechanical grinder. The ground material of the required quantity was soaked for 16 hr. in the desired quantity of water to make the stock solution of the maximum concentration viz. 75 g L^{-1}. The water soaked material was filtered through muslin cloth to obtain the aqueous extract of parthenium leaves. The pallet was squeezed so as to extract all water-soluble material from it and the pallet was then discarded. The lower concentrations were prepared by diluting the stock solution to the required extent and stored in the laboratory for use in the two experiments each with two runs.

Details of test species and treatments

The test species included the crop species (*Triticum aestivum*, *Cicer arietinum*, *Brassica campestris*) and the weed species (*Avena fatua*., *Asphodelus tenuifolius*, and *Lolium rigidum*). Treatments included 0, 25, 50 and 75 g L^{-1} parthenium w/v.

EXPERIMENT 1

Laboratory experiment

The experiment was laid out in a factorial arrangement in a Completely Randomized Design (CRD) with four replications. There were four parthenium extracts (0, 25, 50, and 75 g L^{-1}) (w/v), each applied on three crop species and three weed species. Five seeds each of test species viz. *Triticum aestivum* em Thell, *Cicer arietinum*, *Brassica campestris*, *Avena fatua*, *Asphodelus tenuifolius* and *Lolium rigidum* were soaked with their respective concentration for 24 hours before they were sown and placed on blotting paper in Petri dishes. The blotting paper was kept moist with the respective concentration in each petri dish throughout the duration of the experiment, i.e., three weeks. The crop seeds for both the experiments were procured from the local market, while the weed seeds were availed from the previously collected stock of weed seeds during the previous years and stored in the Department of Weed Science, University of Agriculture Peshawar, Khyber Pakhtunkhwa Province, Pakistan. The whole experiment was conducted twice.

Data recorded in the laboratory experiment

During the course of study, data were recorded on germination percentage (%), root and shoot length per plant (cm), and root and shoot weight per plant (g).

EXPERIMENT 2

Pot experiment

In order to confirm the results of the Lab. experiment, another experiment was conducted in pots using the above protocol viz. factorial arrangement in a Completely Randomized Design (CRD) with four replications. The four treatments in use were 0, 25, 50, and 75 g L^{-1} parthenium extracts and the six species used in the above-mentioned experiment. The concentration of 0 g L^{-1} was used as control for comparison. Plastic pots of 12 cm depth and 15 cm diameter were filled with soil and ten seeds were planted in each pot, which were ultimately thinned to five plants per pot. The seeds were soaked in their respective concentration for 24 hours before sowing and later, in the pots, they were watered with the respective concentration. The experiment was terminated 45 days after planting and the necessary data were recorded. The experiment was repeated once.

Data recorded in the pot experiment

During the course of study the data were recorded on germination percentage (%), fresh and dry biomass per plant (g), plant height (cm) and leaf area per plant (cm^2).

Statistical analyses

The data recorded for the both experiments for each parameter were individually subjected to ANOVA using the MSTATC Software Package to establish differences among the treatment means. The significant means were subjected to the LSD test to decipher the differences among the treatment means (Steel et al., 1997). Since the statistical differences between the runs in each experiment were non-significant for the either of the experiments, the data were pooled before they were subjected to ANOVA and mean separation.

RESULTS AND DISCUSSION

Laboratory experiment

Germination percentage

Statistical analysis of the data showed that parthenium concentrations and species had a significant effect on seed germination, while the interaction between concentrations and species means were non-significant statistically (Table 1). The concentration means showed that there was a slightly stimulatory effect of parthenium extracts at 25 g L^{-1} on seed germination, while an inhibitory response was recorded at higher doses. Pure parthenin treatments in equimolar amounts as present in the extracts could reproduce the stimulatory hormone as a response, which suggests that parthenin may play a key role in eliciting the observed extract hormesis ((Belz, 2007, 2008; Belz, et al., 2016)). Seed germination of the test species decreased with increased concentration of the extract. The lowest germination percentage was recorded in *L. rigidum* and *A. tenuifolius.* For interaction, it was found that, except for wheat, all other test species had poor germination - almost one-fourth of the untreated control at the highest test concentration of parthenium. The data in Table 1 further show that the response of different test species was differential across concentrations of parthenium. These adverse impacts of parthenium residues on growth of test crops could be attributed to the presence of various phytotoxic compounds in parthenium residues viz. water-soluble phenolics including caffeic, ferulic, vanicillic, anisic and fumaric acids, and sesquiterpene lactones including parthenin and coronopilin (Meirse and Singh, 1987). Thus, the present findings suggest preventing parthenium infestation around the crop fields and pastures which could be affected by the allelochemicals released by parthenium (Table 1).

Table 1 - Effect of different concentrations of parthenium extracts on different parameters of different species under laboratory conditions

Test species	Germination (%)				Species means
	Conc. g L^{-1}				
	0	25	50	75	
Triticum aestivum	85.00	91.87	76.25	61.87	78.75 a
Cicer arietimum	73.12	86.25	36.87	20.62	54.21 d
Brassica campestris	72.50	88.75	47.50	18.75	56.87 cd
Avena fatua	87.56	81.25	68.12	32.50	67.34 b
Asphodelus tenuifolius	63.75	70.00	24.37	18.12	44.06 e
Lolium rigidum	80.00	93.75	46.25	19.37	59.84 c
Concentration means	76.97 b	85.31 a	49.89 c	28.54 d	
$LSD_{0.05}$ for concentration means = 2.834, $LSD_{0.05}$ for species means = 3.471					
Triticum aestivum	12.25	11.75	6.00	3.93	8.48 a
Cicer arietimum	3.12	4.00	2.00	1.62	2.68 bc
Brassica campestris	2.18	5.00	1.37	1.18	2.43 c
Avena fatua	11.37	13.37	5.12	3.25	8.28 a
Asphodelus tenuifolius	3.31	5.25	1.87	1.08	2.88 b
Lolium rigidum	3.00	4.81	1.81	1.62	2.81 bc
Concentration means	5.87 b	7.38 a	3.03 c	2.11 d	
$LSD_{0.05}$ for concentration means = 0.3288, $LSD_{0.05}$ for species means = 0.4027					
Root length (cm)					
Triticum aestivum	11.37	13.25	6.41	3.56	8.65 b
Cicer arietimum	10.87	13.50	6.93	4.87	9.04 a
Brassica campestris	3.75	7.75	2.75	1.50	3.18 d
Avena fatua	6.25	8.75	4.75	2.25	5.50 c
Asphodelus tenuifolius	6.50	8.45	4.50	2.50	5.48 c
Lolium rigidum	2.25	4.87	2.77	2.00	2.97 d
Concentration means	6.83 b	8.92 a	4.68 c	2.78 d	
$LSD_{0.05}$ for concentration means =0.2884, $LSD_{0.05}$ for species means =0.3532					
Shoot weight (mg) per plant					
Triticum aestivum	223.50	229.62	143.12	13.00	152.31 a
Cicer arietimum	106.25	13.25	14.12	6.12	34.93 e
Brassica campestris	129.87	139.50	11.00	51.87	83.66b
Avena fatua	49.25	64.25	30.62	22.25	41.59 d
Asphodelus tenuifolius	11.25	12.25	11.87	2.87	9.56 f
Lolium rigidum	69.37	85.75	48.50	34.12	59.4 c
Concentration means	98.25 a	90.77 b	43.20 c	21.70 d	
$LSD_{0.05}$ for concentration means =2.849, $LSD_{0.05}$ for species means =3.489					
Root weight (mg) per plant					
Triticum aestivum	210.75	236.12	159.87	120.25	181.75 a
Cicer arietimum	163.25	197.75	145.87	126.87	158.43 b
Brassica campestris	74.75	81.75	47.00	33.75	59.31 c
Avena fatua	70.25	98.12	70.87	44.29	70.87 d
Asphodelus tenuifolius	89.12	86.75	66.50	51.00	73.34 d
Lolium rigidum	98.62	103.87	78.50	54.125	83.78 c
Concentration means	117.79 b	134.06 a	94.77 c	71.70 d	

$LSD_{0.05}$ for concentration means = 3.985, $LSD_{0.05}$ for species means = 4.881.

Shoot length (cm) per plant

Data in Table 1 show that various concentrations of parthenium significantly decreased shoot length of seedlings of the test species. However, the concentrations and species interaction means were found to be non-significant. Concentration means showed that maximum shoot length of 7.38 cm was found at 25 g L^{-1}, which was greater than shoot length in the control treatment. By increasing the concentration of parthenium extracts beyond the minimum dose, shoot length decreased significantly. The sesquiterpene lactone parthenin produced by certain populations of the invasive weed *P. hysterophorus* is another example for the stimulation/ inhibition properties of some allelochemicals. The compound is biosynthesized during the entire life cycle of the plant, reaching maximum values during generative stages (Reinhardt et al., 2006). It is sequestered in capitate-sessile trichomes on leaves, stems, and the achene-complex of *P. hysterophorus* (Adkins and Sowerby, 1996; Bhowmik and Sarkar, 2005). Parthenin is released from plant material by being washed from ruptured trichomes or from decomposing tissues and it may contribute to the interference of plants with surrounding neighbors. Laboratory studies described the phytotoxic properties of parthenin against a broad range of plant species, including weeds and crops [*e.g. Ageratum conyzoides*, *Amaranthus viridis*, *Avena fatua*, *Cassia tora*, *Chenopodium murale*, *Phaseolus aureus*., and *T. aestivum* (Batish et al.,1997a,b; Datta and Saxena, 2001). The focus of these studies was adverse effects and, thus, recognition of parthenin hormesis was often constrained by the lack of doses below the inhibition range. Among the species, the main effects showed the highest shoot length in *T. aestivum* and *A. fatua.* Rashid et al. (2008) also reported the stimulation of shoot length with a slight dose treatment. Acharya and Rahman (1997) reported that *P. hysterophorus* extracts significantly inhibited germination and establishment in *Cassia tora*, and the effect increased with extract concentration. The leaf extract had the greatest effect in their studies. The present findings suggest that the release of allelochemicals in low amounts stimulates growth, while greater amounts result in inhibition of other plants.

Root length (cm) per plant

The data in Table 1 show that various concentrations of parthenium significantly decreased the root length of the test species; however, the interaction of concentrations x species were found to be non-significant statistically. Concentration means showed that the highest root length was found in the 25 g L^{-1} parthenium extract while there was a decrease with increased concentrations. The data reveal that the inhibitory effect of different concentrations was more pronounced for shoot as compared to root. Root length of maize and sorghum decreased with increasing concentration of parthenium root extracts (Rashid et al., 2008). Parthenin; the major allelochemical causing the bioactivity is the question of the ecological significance and possible cause of hormesis (stimulation at lower dose). Parthenin can be released by leaching from living plant parts or by decomposition of plant residues (Reinhardt et al., 2006; Belz, 2016). While the latter mode of release is believed to release inhibitory levels of parthenin, it is still unknown if leaching of parthenin by rain, mist or dew is of enough magnitude to cause a biological effect, whether stimulatory or inhibitory. Dropping of parthenin-containing leachates on leaves of target plants growing under the canopy of *P. hysterophorus* may be one mechanism of the plant's allelopathic capacity. The literature reports from other plant species demonstrated that such natural leachates can exhibit inhibitory allelopathic effects, *e.g. Acacia dealbata* (Msafiri et al., 2013). Inhibition of root length shows that parthenium can thrive successfully and can replace native flora because of its allelopathic potential, which is a threat to biodiversity (Zuberi et al., 2014).

Shoot weight (g) per plant

There was a significant effect of various concentrations of *P. hysterophorus* on shoot weight of different crops and weeds. The interaction means were found to be non-significant statistically. The data revealed that there is a slight stimulation of shoot weight at the low dose application of parthenium extracts which agrees with the previous work showing the differential response of species to the allelochemicals depending on varying sensitivity among the test species (Belz, 2008, 2016). Shoot weight decreased as the concentration increased. Concentration means showed that the highest value (98.25 g) was found in the control. The species means indicated that *A. tenuifolius* was found to be the most vulnerable to the allelochemicals. Hence, the present findings suggest that parthenium can be utilized to control different weeds while further extensive studies are required to explore the allelopathy process under different temperature regimes and ecological zones as well as the fine-tuned response of different crops and weeds.

Root weight (g) per plant

Statistical analysis of the data (Table 1) revealed that parthenium extracts significantly decreased the root weight of the test species. The interaction means were found to be non-significant statistically, however. Concentration means indicated that the highest root weight was recorded in the lowest parthenium extract i.e. 25 g L^{-1} while minimum root weight was recorded under the highest concentration regime of the parthenium extracts (Table 1). Batish et al. (1997a,b) and Belz (2016) also investigated the bioactivity of parthenin in a spray application, but they did not find hormetic effects, as the doses in use were inhibitory. In another study, the magnitude of hormesis on *S. arvensis* was in the range of average hormesis responses observed for various herbicides in plants and algae (20-30%) (Carballeira et al., 1999; Cedergreen et al., 2007). However, maximum hormesis effects by parthenin on root length in germination assays reached higher values of up to 82% stimulation when using *Eragrostis curvula* and *Echinochloa crus-galli* as the test species (Belz et al., 2007). The results indicated that areas highly infested with parthenium can accumulate a greater amount of allelochemicals and thus it can prove detrimental to different crops (Zuberi et al., 2014).

Pot experiment

Germination percentage (%)

The statistical analysis of data revealed that various concentrations of parthenium significantly (á = 0.05) affected the germination of all the test species (Table 2). There was a slight inhibitory effect on germination of *T. aestivum* while the inhibitory effect on the rest of the species was comparatively greater. With the increasing concentration of parthenium, the germination of *A. fatua* and *A. tenuifolius* decreased (Hassan et al., 2008). *P. hysterophorus* extracts significantly inhibited the germination of *Eragrostis tef* (Tefera, 2002) because of the release of phytotoxins from parthenium leaves (Adkins and Sowerby, 1996). The results revealed that *C. arietinum* was more prone to the higher concentration of parthenium extract. Species-specific difference in sensitivity to aqueous leaf extracts of fresh and dry leaf material of *P. hysterophorus* was reported in previous studies (Meirse et al., 1987; Khaliq et al., 2016). The results indicated that areas highly infested with parthenium can accumulate a greater amount of allelochemicals and, thus, can pose harmful effects for wheat and other crops (Khaliq et al., 2016).

Fresh biomass (g) per plant

The data indicated that fresh biomass of the test crops and weeds decreased with increasing concentrations of parthenium extracts (Table 2). The concentration means show that species treated with 25 g L^{-1} had the highest biomass (9.37 g), which is even higher than the control. The stimulatory effect of parthenium aqueous extracts has been reported as result of hormesis (Rashid et al., 2008; Batish et al., 1997b; Belz, 2016). Among the species means, *A. tenuifolius* was found to be prone to the allelohemicals with the lowest fresh biomass of only 1.84 g per plant as a result. Many researchers (Datta and Saxena, 2001; Tefera, 2002; Maharjan et al., 2007) reported the importance of parthenium as a herbicide. Likewise, Singh et al. (2005) reported adverse effects of parthenium residues on growth of *Brassica campestris*, *B. oleracea* and *B. rapa.* A similar adverse impact of parthenium residues has also been reported by Batish et al. (2002). These adverse impacts of parthenium residues on growth of test crops could be attributed to the presence of various phytotoxic compounds in Parthenium residues viz. water-soluble phenolics including caffeic, ferulic, vanicillic, anisic and fumaric acids, and sesquiterpene lactones including parthenin and coronopilin (Reinhardt et al., 2006). The magnitude of hormesis on

Table 2 - Effect of different concentrations of parthenium extracts on different parameters of different species grown in pots

Test species	Germination (%) Conc. g L^{-1} 0	25	50	75	Species mans
Triticum aestivum	92.50	87.50	62.50	37.50	70.00 ab
Cicer arietimum	95.00	70.00	55.00	37.50	64.30 b
Brassica campestris	90.00	82.50	57.50	25.00	63.75 b
Avena fatua	90.00	90.00	72.50	40.00	73.12 a
Asphodelus tenuifolius	87.50	77.50	82.50	32.50	70.00 ab
Lolium rigidum	92.50	70.00	52.50	45.00	65.00 b
Concentration means	91.25 a	79.98 b	63.75 c	36.25 d	
$LSD_{0.05}$ for concentration means = 5.252, $LSD_{0.05}$ for species means =6.432					
Fresh biomass (g)					
Triticum aestivum	10.71	14.21	18.58	3.68	11.79 a
Cicer arietimum	8.42	5.21	3.62	2.32	4.89 d
Brassica campestris	8.62	12.76	4.10	2.31	6.95 c
Avena fatua	7.65	11.25	4.75	4.15	6.95 c
Asphodelus tenuifolius	1.81	2.75	1.41	1.40	1.84 e
Lolium rigidum	12.11	10.06	7.85	4.55	8.64 b
Concentration means	8.22 b	9.37 a	6.72 c	3.07 d	
$LSD_{0.05}$ for concentration means =0.332, $LSD_{0.05}$ for species means =0.389					
Dry biomass (g)					
Triticum aestivum	1.87	2.16	2.35	1.53	1.98 a
Cicer arietimum	1.93	0.99	0.74	0.36	1.01 d
Brassica campestris	0.82	1.63	0.65	0.44	0.88 d
Avena fatua	1.74	2.15	2.15	0.75	1.70 b
Asphodelus tenuifolius	0.26	0.10	0.12	0.07	0.14 e
Lolium rigidum	1.92	1.78	1.32	0.89	1.48 c
Concentration means	1.42 a	1.47 a	1.22 b	0.67 c	
$LSD_{0.05}$ for concentration means =0.122, $LSD_{0.05}$ for species means =0.150					
Plant height (cm)					
Triticum aestivum	23.46 b	28.88 a	23.75 b	12.68 d	22.19 a
Cicer arietimum	12.71 d	13.88 cd	7.46 gh	5.75 gh	9.54 c
Brassica campestris	8.78 fg	12.21 def	6.55 gh	5.15 h	8.17 c
Avena fatua	21.38 b	17.21 c	13.88 cd	12.55 de	16.25 b
Asphodelus tenuifolius	9.06 efg	12.19 def	7.60 gh	5.73 gh	8.64 c
Lolium rigidum	12.13 def	13.27 d	8.39 gh	6.08 gh	9.97 c
Concentration means	14.59 b	16.27 a	11.27 c	7.99 d	
$LSD_{0.05}$ for conc.means = 3.616, $LSD_{0.05}$ for species means =1.808, $LSD_{0.05}$ for interaction means = 1.476					
Leaf area (cm^2)					
Triticum aestivum	99.41	111.70	82.05	53.30	86.61 a
Cicer arietimum	70.00	52.12	36.100	22.82	45.46 c
Brassica campestris	49.57	77.50	39.71	15.83	45.67 c
Avena fatua	79.30	111.62	67.20	48.85	76.74 ab
Asphodelus tenuifolius	18.02	16.83	11.15	6.86	13.40 d
Lolium rigidum	9.02	75.15	66.27	61.10	72.88 b
Concentration means	67.68 a	74.30 a	50.41 b	34.79 c	

$LSD_{0.05}$ for concentration means = 8.834, $LSD_{0.05}$ for species means = 11.02. Means in t sharing a letter in common in the respective category do not differ significantly by LSD at $P_{0.05}$.

S. arvensis in this study was in the range of average hormesis responses observed for various herbicides in plants and algae (20-30%) (Cedergreen et al., 2007). However, maximum hormesis effects by parthenin on root length in germination assays reached higher values of up to 82% stimulation using *Eragrostis curvula* and *Echinochloa crus-galli* as test species (Belz et al., 2007).

Dry biomass (g) per plant

Statistical analysis of the data showed that different concentrations had a significant effect on dry biomass of the test species (Table 2). The data indicated that higher concentrations effectively inhibited dry biomass of the test species as compared to lower concentrations. The early growth of crops, measured in terms of seedling length and dry weight, was significantly reduced when grown in soil amended with varying amounts of parthenium residues (Singh et al., 2005). The highest dry biomass (1.98 g) was recorded for *T. aestivum* while the lowest dry biomass (0.14 g) was recorded for *A. tenuifolius. P. hysterophorus* extracts significantly inhibited germination and establishment in *Cassia tora* and the effect increased with the increased extract concentration, while the leaf extract had the greatest effect (Acharya and Rehman, 1997). Comparing the values in the control with the treated plots, there is convincing evidence of the presence of allelochemicals in Parthenium extracts that can selectively affect weeds and crops. However, more meaningful results could be found if plant allelopathy were studied under various environmental conditions.

Plant height (cm) per plant

The analysis of data in Table 2 shows that the main effects of parthenium extracts and the test species had a statistically significantly effect in all the study parameters while the interaction between parthenium extracts x species decreased the plant height of the test species. Plant height of all the test species decreased with the increasing concentrations of parthenium extracts. The release of parthenin during decomposition of leaf material has a potential to play a leading role for allelopathy in *P. hysterophorus*; however, its significance in a natural setting will greatly rely on the amount of leaf material accumulated on soil surfaces and concentration of parthenin in residues (Reinhardtet al., 2006). Species means indicates that the highest plant height (22.19 cm) was recorded in *T. aestivum* while the lowest plant height was recorded in *C. arietimum* and *B. campestris*, which were statistically at par with each other. The present study suggests that the presence of Parthenium can accumulate a great amount of toxic chemicals to the soil, thus affecting the subsequent crops negatively. Hence, Parthenium infestation should be discouraged to salvage the crops from yield losses.

Leaf area (cm^2) per plant

Statistical analysis of the data showed that with increasing concentration of *Parthenium*, the leaf area was decreased slightly (Table 2). The concentration means indicated that the highest leaf area of 74.30 cm^2 was measured in *T. aestivum*. By contrast, among the test concentrations, the lowest leaf area was recorded in the 75 g L^{-1} extract. These adverse impacts of parthenium residues on growth of test crops could be attributed to the presence of various phytotoxic compounds in parthenium residues. Singh et al. (2002, 2005) reported adverse effects of parthenium residues on the growth of *B. campestris*, *B. oleracea* and *B. rapa.* A similar adverse impact of parthenium residues has also been reported by Batish et al. (2002) on the growth of *Cicer arietinum* and *Raphanus sativus.* Similarly, Dhole et al. (2011) found an inhibitory effect of parthenium extracts on cotton, wheat, maize and sorghum. There is convincing evidence of the presence of allelochemicals in parthenium extracts that can selectively affect weeds and crops.

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