

## Herbicidal potential of allelopathic plants and fungi against *Parthenium hysterophorus* – A review

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### ABSTRACT

*Parthenium* (*Parthenium hysterophorus* L.) is world's worst weed. It is native to tropical America and has rapidly spread in Asia, Africa, Australia and Europe. It can be controlled by herbicides, but their use adversely affects the environment and human health. Hence, alternate eco-friendly, cost effective and bioefficacious methods of weed control are needed. Efforts are being made to use natural plant products for weed management. It has been shown that extracts, residues and essential oils of many allelopathic plant species (herbs, grasses and trees) effectively reduce the germination and growth of parthenium. Likewise metabolites of many fungal species have herbicidal effects on its germination and growth. There is need to isolate and identify the active herbicidal ingredients from plants and fungal metabolites. These chemical constituents may provide the structural lead to prepare natural product based environment friendly herbicides to manage this weed.

**Key words:** Alien weed, allelopathy, fungal metabolites, management, *Parthenium hysterophorus*.

### 1. INTRODUCTION

In allelopathy, one plant exerts a detrimental influence on another through the production of germination and growth inhibiting substances in crops (67), grasses (24),

weeds (36) and trees (4). It is an important ecological process in vegetational composition and agricultural sciences (8,27), and governs the plants productivity (65). It plays important role in plant diversity (12), adaptation of species, organisation of communities and in species evolution (40). It is a tool of self-defense in plants, helping to defend against invading insects and other neighbouring plants (47). Recent advances in plant biology have explained the plant invasion and plant-plant communication in rhizosphere (81). Allelochemicals are secondary metabolites produced via the acetate and shikimic acid pathways and produces phenolic acids, coumarins, flavonoids, terpenoids, alkaloids and sulfides (11,57). They affect all basic plant processes [photosynthesis, chlorophyll production, respiration, hormonal balance, protein synthesis and plant water relations (84)]. They enter the soil (through rain leachates from foliage, root exudation and decomposition of plant residues or as microbial by-products of residue decomposition) and selectively inhibit the growth of other plants and soil microorganisms (17). Originally classified as waste products, recently allelochemicals are investigated extensively by ecologists and pharmacologists for many complex biological functions (22). Allelopathic properties of plants can be used to control pathogens and weeds (6,68).

Comexistin is a nonadride phytotoxin from the coprophyllic basidiomycete *Paecilomyces variotii* with good herbicidal activity against monocotyledonous and dicotyledonous weeds, however, maize is resistant to it (55). Two phytotoxic metabolites (prehelminthosporal and dihydropore) from the cultural filtrates of *Bipolaris* sp. are herbicidal against *Sorghum helepense* (54). Similarly, trans-4 aminoproline isolated from *Ascochyta caulina*, effectively controls the *Chenopodium album* (19). A new phytotoxic trisubstituted naphthofuroazepinone [named drazepinone, and characterized it as a 3,5,12 a-trimethyl-2,5,5a,12a-tetrahydro-1*H*-naphtho[2',3':4,5]furo[2,3-*b*]azepin-2-one] from *Drechslera siccans*, at 2  $\mu\text{g } \mu\text{l}^{-1}$  showed broad-spectrum herbicidal properties (20).

Parthenium (*Parthenium hysterophorus* L.), an annual invasive weed of family Asteraceae, is native to tropical America and has invaded North America, South America, the Caribbean, and many parts of Africa, Asia, and Australia (58). It is very prolific seed producer and produces up to 25,000 seeds per plant (58), leading to large seed bank of about 200,000 seeds  $\text{m}^{-1}$  in fields (41). Furthermore, seeds germinate throughout the year given suitable moisture levels and remain viable for long time and thrive under very harsh environmental conditions (82). The weed also has a very high regenerative potential (14). The weed is highly adaptive to adverse environmental conditions, and is a successful invader of any open land. The plants commence flowering, when 4 to 8 weeks old and may flower for several months. Under drought stress the weed can germinate, grow, mature and set seeds in 4-weeks. It was accidentally introduced to India in the mid-1960s through imported food grains (9) and has since spread throughout the Indian sub-continent, including Pakistan. In Pakistan it has spread in Punjab, North Western Frontier Province and Kashmir and replaced the local flora. Now it has become naturalized and grows luxuriantly in open spaces, grasslands, wastelands, around the fields and sometimes also in cultivated fields (29,33). Its invasive nature is evident from its ability to form huge monocultural stands with no other plant in the vicinity. It causes numerous environmental and agricultural problems (loss of crop productivity, fodder scarcity, biodiversity depletion) and health problems for human beings and livestock (18,52). In native Australian grasslands, open woodlands, river banks and floodplains, parthenium invasion has totally changed the habitat (52). Similar invasion of national wildlife parks has

occurred in south India (18). In artificial feeding tests, buffalo bull calves accepted the weed, alone or in mixture with green fodder, with severe consequences. The majority developed severe dermatitis and toxic symptoms and died within 8-30 days. Lesions were found subsequently in the gastrointestinal tract, liver and kidneys (56). Changes in blood chemistry and inhibition of liver dehydrogenases, as well as degenerative changes in both the liver and kidneys have been reported in buffalo and sheep (3). The milk of livestock may also be tainted by parthenin (77). Its various parts contain water soluble phenolics including caffeic, ferulic, vanillic, anisic and fumaric acids, and sesquiterpene lactones including parthenin and coronopilin, (7,62) and acetylated pseudoguaianolides (15).

Chemical herbicides [chlorimuron ethyl, metasulfuron methyl (53), 2, 4-D sodium salt, MCPA, MSMA (51), chxwastox, butrill super (32), atrazine, ametryn, bromoxynil+MCPA and glyphosate] are effective against parthenium (28). However, in recent years, the use of chemicals has increased consumer's concern and their use is becoming more restrictive due to various problems viz., carcinogenic effects, residual toxicity problems, environmental pollution, and occurrence of microbial resistance (64). Increasing public concern has led the scientist to develop alternative pest management systems, which are less pesticide dependant or based on natural compounds (13). Use of biological control agents could be environmentally safe strategy to control this weed but only few potential biological control agents have been reported. Thus weed biologists have screened various allelopathic plant species and fungal metabolites for their herbicidal effects against this weed, so that effective ingredients from them can be isolated to develop natural compound based herbicidal formulations to control it. This review presents the herbicidal activities of various plants and fungal metabolites against the parthenium weed.

## 2. PLANT SPP.

Numerous plants are allelopathic and these should be used in agriculture for weed management. Herbicides based on natural products are attractive because they exhibit bioactivity at low concentrations. Besides their mode of actions are different than commercial herbicides, making them ideal lead compounds for new herbicide discovery (79). Crude extracts, plants residues and purified compounds of allelopathic plants (crops, grasses, broad-leaf weeds and trees) have shown their herbicidal activity against germination and growth of parthenium (Table 1).

### 2.1. CROPS

**2.1.1 Rice:** Rice (*Oryza sativa* L.) is a well known allelopathic crop (37,45). Its aqueous root and shoot extracts reduces the germination and root growth of parthenium weed (33). Different rice varieties exhibit variable phytotoxic effects against germination and growth of parthenium. Similar to that of rice extracts, incorporation of rice residue also reduced the germination and growth of parthenium (37). The living and dead rice plants release different allelochemicals. Allelochemicals from living rice plants are: Momilactones A and B, 3-isopropyl-5-acetoxycyclohexene-2-one-1 and 5,7,4'-trihydroxy- 3",5"-dimethoxy-flavone. Allelochemicals from rice residues are: Momilactone B and phenolic acids (*p*-hydroxybenzoic, *p*-coumaric, ferulic, syringic and vanillic acids) (45).

Table 1. Phytotoxic effects of allelopathic plants and fungal metabolites on parthenium weed

Name of crop	Plant part studied	Allelochemicals Present	Suppression/Inhibitory effect (s)	References
<b>A. Crops</b>				
<i>Oryza sativa</i>	Root and shoot	Momilactones A and B, phenolic acids, 5,7,4'-trihydroxy-3",5"-dimethoxyflavone, and 3-isopropyl-5-acetoxy cyclohexene-2-one-1	Reduced germination and root/shoot growth	Javaid <i>et al.</i> (33, 37), Kato-Noguchi <i>et al.</i> (45)
<i>Sorghum bicolor</i>	Root and shoot	Benzoic, <i>p</i> -hydroxy benzoic, vanillic, <i>m</i> -coumaric, <i>p</i> -coumaric, gallic, caffeic, ferulic and chlorogenic acids	Reduced germination and root/shoot growth	Cheema (10), Javaid <i>et al.</i> (33),
<i>Helianthus annuus</i>	Root and leaves	phenols and terpenoides	Reduced germination and root growth	Javaid <i>et al.</i> (33), Macias <i>et al.</i> (49,50)
<b>B. Grasses</b>				
<i>Imperata cylindrica</i>	All parts	Caffeic, ferulic, <i>p</i> -hydroxybenzoic, <i>p</i> -coumaric, vanillic, chlorogenic and syringic acids	Reduced germination and root/shoot growth	Anjum <i>et al.</i> (5), Hussain and Abidi (24)
<b>C. Broad-leaf Weeds</b>				
<i>Breynia retusa</i>			Chlorosis, necrosis and defoliation	Rani <i>et al.</i> (63)
<i>Cassia tora</i>	Leaves		Reduced vegetative and reproductive growth	Thapar and Singh (75)
<i>Cannabis sativa</i>	Leaves		Reduced germination, biomass, protein and pigment content	Singh and Thapar (73)
<i>Withania somnifera</i>	Leaves and roots	Withaferin A	Reduced germination and plant growth	Javaid <i>et al.</i> (39) Kalthur <i>et al.</i> (42)
<b>D. Trees</b>				
<i>Alstonia scholaris</i>	Leaves	indole alkaloids (19,20-( <i>E</i> )-vallesamine, angustilobine B <i>N</i> <sup>4</sup> -oxide, 20( <i>S</i> )-tubotaiwine, 5- <i>epi</i> -nareline ethyl ether and 6,7- <i>seco</i> -angustilobine B)	Reduced germination and plant growth	Javaid <i>et al.</i> (34), Kam <i>et al.</i> (43), Macabeo <i>et al.</i> (48)
<i>Eucalyptus citriodora</i>	Leaves	phenolic acids, tannins, flavonoides, and eucalypt oils	Reduced germination	Javaid and Shah (35), Shiva and Bandyopandhyay (71)
<i>Eucalyptus globulus</i>	Leaves	Monoterpenes (cineole, citronellol, citronellal and linalool),	Reduced germination and chlorophyll content	Kohli <i>et al.</i> (46), Singh <i>et al.</i> (72)
<i>Azadirachta indica</i>	Leaves	gallic, benzoic, <i>p</i> -coumaric, <i>p</i> -hydroxybenzoic, vanillic, and <i>trans</i> -cinamic acid	Reduced germination and dry biomass	Shafique <i>et al.</i> (64) Xuan <i>et al.</i> (83)

**E. Fungi**

<i>Alternaria alternata</i>	Culture filtrates	AAL-toxin	Reduced germination and root/shoot growth	Abbas <i>et al.</i> (1), Javaid and Adrees (38)
<i>Phoma herbarum</i>	Culture filtrates	3-nitro-1,2-benzenedicarboxylic acid	Necrosis of leaves	Vikrant <i>et al.</i> (78)
<i>Fusarium equiseti</i> , <i>Macrophomina phaseolina</i> , <i>Drechslera rostrata</i> , <i>Fusarium oxysporium</i>	Culture filtrates	Not known	Reduced germination and seedling growth	Idrees and Javaid (25), Javaid and Adrees (38)

**2.1.2. Sorghum:** Aqueous shoot and root extracts of sorghum (*Sorghum bicolor* L.) are highly toxic to germination and seedling growth of parthenium. Shoot extract was more toxic than root extract (33). Sorghum contains nine allelochemicals [Benzoic acid, *p*-hydroxy benzoic acid, vanillic acid, *m*-coumaric acid, *p*-coumaric acid, gallic acid, caffeic acid, ferulic acid and chlorogenic acid], which are phytotoxicity to weeds (10). Sorgoleone exuded from the sorghum roots (59) suppresses the growth of weeds (21).

**2.1.3. Sunflower:** The shoot and root extracts (5-25%) of sunflower (*Helianthus annuus* L.) significantly reduced the germination and root growth of parthenium (33). Several phenols and terpenoids (7,11-heliannane, annuolide E, leptocarpin, annuionone E, heliannuol L, helibisabonol A and helibisabonol B) have been reported as potential allelochemicals in various cultivars of sunflower (50). The heliannuols are a promising group of phenolic allelochemicals isolated from sunflower (49), which may be responsible for reduction of germination and growth of parthenium.

**2.2. GRASSES**

Certain grass species [Floren bluegrass (*Dicanthium aristatum*), Digit grass (*Digitaria milanjiana*) Buffel grass (*Cenchrus ciliaris*) and Bisset bluegrass (*Bothriochloa insculpta*)] effectively displaced the parthenium weed (60). The frequency and density of parthenium was significantly lower in *Imperata cylindrica* (L.) Beauv. and *Desmostachya bipinnata* Stapf. dominating localities than nearby areas without infestation of these allelopathic grasses (5,30). Further studies revealed that aqueous root and shoot extracts of *I. cylindrical*, *D. bipinnata* and other allelopathic grasses [*Dicanthium annulatum* Stapf., *Cenchrus pennisetiformis* Hochest and *Sorghum halepense* Pers.] reduce the germination and seedling growth of parthenium (5,30,31). The inhibitory effects were concentration dependant. Shoot extracts were generally more inhibitory than root extracts (Table 2). Thus water-soluble chemicals of allelopathic grasses are herbicidal to the parthenium weed. The allelopathic grasses contain various phenolics [Caffeic, ferulic, *p*-hydroxybenzoic, *p*-coumaric, vanillic, chlorogenic and syringic acids] (24) which may suppress the germination and growth of parthenium.

Table 2. Effects of aqueous root and shoot extract of five allelopathic grasses on germination and early seedling growth of *Parthenium hysterophorus*.

Grass species	Treat-ments	Germi-nation %	Shoot extract			Fresh Wt. (mg)	Germ. %	Root extract			Fresh Wt. (mg)
			Shoot Length (cm)	Root Length (cm)	Fresh Wt. (mg)			Shoot Length (cm)	Root Length (cm)	Fresh Wt. (mg)	
<i>Sorghum helipense</i>	0%	100a	1.85b	1.9a	8.2a	100a	1.85a	1.9ab	8.2a		
	5%	100a	2.11a	1.11de	7.4ab	100a	1.18bc	1.97a	7.7a		
	10%	100a	2.11a	0.99ef	7.6ab	100a	0.93bcd	1.64b	5.8cde		
	15%	100a	1.81bc	0.96f	5.98cde	70cd	0.89cde	1.33c	4.5gh		
	20%	70b	1.69bcd	0.95f	6.16cd	75bc	0.70def	1.10cde	4.0hi		
	25%	60bcd	1.37e	0.87f	5.0efg	55efg	0.60ef	0.80g	3.2ij		
<i>Imperata cylindrica</i>	5%	69b	1.67bcd	1.76ab	6.3cd	70cd	1.79a	1.85ab	7.58ab		
	10%	60bcd	1.41e	1.13de	5.1efg	76bc	1.54a	1.31cd	6.6bc		
	15%	52cde	1.43e	0.97f	4.9fg	64cdef	1.24b	0.90fg	5.7cdef		
	20%	45ef	1.11f	0.85f	3.8hi	60defg	1.02bcd	0.97efg	5.4defg		
	25%	20h	0.10g	0.24h	0.94k	52fg	0.95cde	0.85fg	4.73fgh		
	5%	65bc	1.8bc	1.72b	6.6bc	85b	1.77a	1.93a	8.0a		
<i>Dicanthium annuatum</i>	10%	46def	1.6cde	1.52c	4.6gh	65cde	1.74a	1.81ab	6.3cd		
	15%	42ef	1.35e	1.45c	3.6i	58defg	1.22b	1.65b	4.8efgh		
	20%	35fg	0.16g	0.37h	2j	35h	0.37fg	0.80g	2.8jk		
	25%	23gh	0.11g	0.10i	0.0k	27h	0.14gh	0.32hi	0.9l		
	5%	60bcd	1.77bc	1.87ab	8.1a	60defg	1.81a	1.93a	8.5a		
	10%	47def	1.51de	1.51c	6.4cd	50g	1.22b	1.68a	7.8a		
<i>Cenchrus pennisetiformis</i>	15%	13hi	0.97f	0.63g	5.6defg	37h	1.22b	1.06def	5.8cde		
	20%	00i	0.0g	0.0i	0.0k	10i	0.45fg	0.1ij	2.0k		
	25%	00i	0.0g	0.0i	0.0k	00i	0.0h	0.0j	0.0l		
	5%	55cde	1.38e	1.80ab	6.2cd	85b	1.8a	1.70ab	7.5ab		
	10%	45ef	45bcd	1.61d	1.25cde	50g	1.68a	1.36c	6.4cd		
	15%	20h	1.06f	0.31h	2.6j	10i	0.84e	0.53h	2.3kl		
<i>Desmostachya bipinnata</i>	20%	00i	0.0g	0.0i	0.0k	00i	0.0h	0.0j	0.0l		
	25%	00i	0.0g	0.0i	0.0k	00i	0.0h	0.0j	0.0l		
	5%	00i	0.0g	0.0i	0.0k	00i	0.0h	0.0j	0.0l		

Values with different letters in a column show significant difference ( $P \leq 0.05$ ) as determined by Duncan's Multiple Range Test. Sources: Javaid *et al.* [28], Javaid and Anjum [29]

### 2.3. BROAD-LEAF WEEDS

*Cassia tora* is a legume (subfamily Caesalpinioideae) and grows wild in tropics and is considered a weed in many places. Its powdered leaves adversely affected the growth of parthenium up to 60 days after sowing. It reduced the plant height, leaf size and number of branches, capitula and seeds per plant. The total sugars and lipids were decreased both in leaf and stem of parthenium plants supplied with *C. tora* residues (75).

The leaf residue of *Croton bonplandianum* decreased the leaves size and seedling height of parthenium (76). The number of leaves, branches, capitula and seeds/plant were decreased. The inhibition of growth was due to decrease in chlorophyll, sugars, protein and lipid contents, while organic and amino acids were increased.

Singh and Thapar (73) evaluated the phytotoxic effects of leaf leachates of female plants of *Cannabis sativa* on morphological and biochemical parameters of parthenium. Dry leaf leachates of *C. sativa* caused maximum reduction in biological activities in parthenium. The leachates reduced the seed germination, fresh weight and pigment content of the test plant. The protein content and nitrate reductase activity followed a decreasing trend with an increase in concentration of leaf leachates.

Foliar application of water extract of *Breynia retusa* caused chlorosis and necrosis in the parthenium plants. Its crude leaf extract acted as contact herbicide. The extract initially killed only the parts of the plant that were sprayed/exposed to extract but later the entire plant was defoliated (63).

Aqueous and methanol extracts of roots and leaves of *Withania somnifera* (L.) Dunal., Solanaceae—a medicinal plant markedly suppressed the germination, root and shoot growth of parthenium in laboratory bioassay. Foliar spray of these extracts (10% w/v) significantly reduced shoot length and biomass. Incorporation of its dry leaves in soil at 1, 2, 5% can reduce parthenium seed germination by 43–89% (39). The major chemical constituents reported from *W. somnifera* are withanolides and the most important one is withaferin A, a highly oxygenated steroidal lactone. *W. somnifera* also possesses other secondary metabolites viz., flavonol glycosides, glycowithanolides, sterols and phenolics (44). One or more of these compounds may be responsible for herbicidal activity of *W. somnifera* against parthenium weed. Withaferin A has cytotoxic and inhibitory action on protein synthesis (42).

The extracts of *Calotropis procera*, *Artemisia annua* and *Physalis minima* also possess phytotoxic constituents that can be used as bioherbicides to control parthenium weed (69,74).

### 2.4. TREES

Aqueous leaf extracts of *Alstonia scholaris* (L.) R. Br. inhibited the germination and growth of parthenium both in laboratory bioassays and in pot experiments (34). Its leaves contain many indole alkaloids [19,20-(*E*)-vallesamine, angustilobine B *N*<sup>1</sup>-oxide, 20(*S*)-tubotaiwine, 5-*epi*-nareline ethyl ether and 6,7-*seco*-angustilobine B] (48), which may be responsible for the herbicidal activity of its aqueous extracts (23). Its leaves collected in Pakistan, India, Philippines, Thailand, Malaysia, and Indonesia showed diverse alkaloidal patterns. The trees from Pakistan, India and Thailand contain picrinine-type alkaloids, while those from Indonesia and the Philippines contain alkaloids based on the angustilobine skeleton (43,48).

*Eucalyptus citriodora* Hook is a well known allelopathic tree (71). Aqueous leaf extracts of *E. citriodora* and *E. camaldulensis* Dehnh reduced the germination, and root and shoot growth of parthenium (35) due to the allelochemicals (phenolic acids, tannins and flavonides) present in their leaves (71). Eucalypt oils from *Eucalyptus globulus* and *E. citriodora* exerted deleterious effects on parthenium weed (46). The weed germination was inhibited and the chlorophyll content and cellular respiration of the mature plants exposed to eucalypt oils were reduced drastically, followed by complete wilting of plants after 15 days. The *E. citriodora* oil was more effective than *E. globulus* oil (46). The monoterpenes (cineole, citronellol, citronellal, and linalool), the constituents of eucalypt oil, decreased the photosynthesis by reducing chlorophyll content (66,72). Interference of monoterpenes with respiratory ability decreases the germination and growth of plants (2). The insolubility of monoterpenes, in water limits their toxicity to other plants. However, monoterpenes are generally active at concentrations far below their maximum solubility (80). However, these can be brought into solution form with some surfactants (54) to manage parthenium and other weeds.

Shafique *et al.* (70) assessed the herbicidal activity of aqueous extracts (2,4,6,8,10%) of dry leaves of *Ficus bengalensis* L., *Azadirachta indica* (L.) A. Juss, *Melia azadarach* L., *Mangifera indica* L. and *Syzygium cumini* (L.) Skeels against parthenium seeds germination in lab bioassays. The 8 and 10% extracts of these tree species significantly suppressed the germination of parthenium seeds. Extracts of *F. bengalensis* and *M. indica* were found most inhibitory and those of *M. azedarach* were least inhibitory to radicle and plumule growth of parthenium.

### 3. FUNGAL METABOLITES

Data regarding the herbicidal activity of culture filtrates of various fungal species against parthenium is summarized in Table 1. Dhanaseeli and Sekar (16) isolated various soil-borne fungi and found that methanolic fractions of these fungi were highly phytotoxic to parthenium. Idrees and Javaid (25) studied the effect of metabolites of seven phytopathogenic fungi [*Ascochyta rabiei*, *Cladosporium oxysporum*, *Macrophomina phaseolina*, *Drechslera hawaiiensis*, *Drechslera tetramera*, *Fusarium equiseti* and *Phoma glomerata*] against germination and early seedling growth of parthenium weed. Metabolites of all the tested fungal species suppressed the germination and reduced the root and shoot growth of the target weed. Metabolites of *C. oxysporum* were most inhibitory to germination of parthenium followed by metabolites of *M. phaseolina* and *F. equiseti* (Fig. 1). Likewise Javaid and Adrees (38) evaluated the herbicidal activity of nine phytopathogenic fungal species [*Alternaria alternata*, *Drechslera australiensis*, *Drechslera hawaiiensis*, *Drechslera bisepitata*, *Drechslera rostrata*, *Fusarium oxysporum*., *Fusarium solani*, *Monilia stophila* and *Cladosporium* sp.]. Culture filtrates of *Alternaria alternata*, *Cladosporium* sp. and *Drechslera rostrata* drastically reduced the seed germination of parthenium by 90, 73 and 50%, respectively. Culture filtrates of these and other fungal species [*Drechslera australiensis*, *Fusarium oxysporium* and *F. solani*] significantly reduced the root and shoot length of parthenium seedlings. *A. alternata* contains AAL-toxin with herbicidal activity (1). Metabolites of *Phoma herbarum* exhibited herbicidal properties against parthenium weed and the toxic metabolite was identified as 3-nitro-1,2-benzenedi-carboxylic acid (3-nitroptaalic acid) (78).

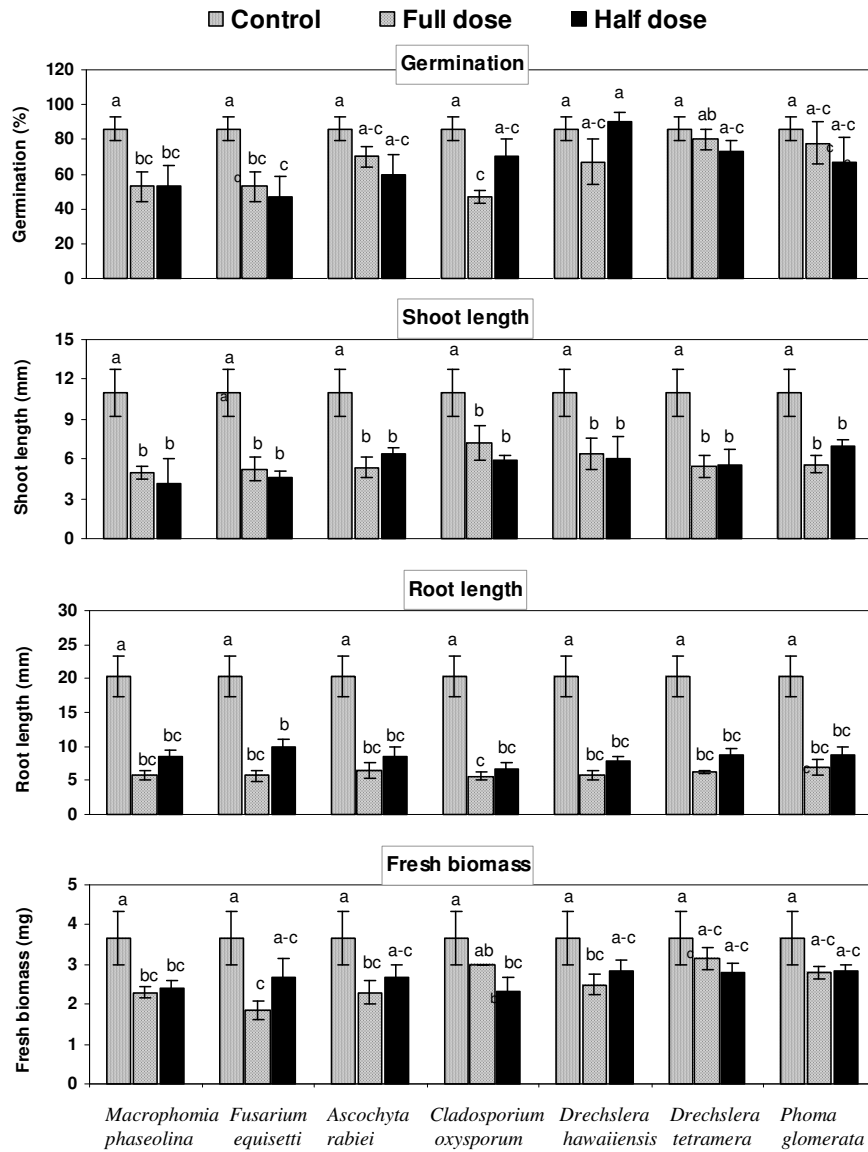


Figure1. Effects of full (100%) and half (50%) doses of metabolites of plant pathogenic fungi on germination and early seedling growth of *Parthenium hysterophorus*, in laboratory bioassays. In a column, values with different letters show significant ( $P \leq 0.05$ ) difference as determined by Duncan's Multiple Range Test. Source: 23.

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