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ORIGINAL ARTICLE

Control of wild oat (*Avena fatua*) using some phenolic compounds I – Germination and some growth parameters

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Abstract The percentage of germination of wild oat was significantly inhibited by increasing the concentrations of phenolic compounds. Ferulic acid was the most effective compound which completely inhibited germination at a concentration of 3.0 mM. At the same time, wheat and barley were slightly affected with different concentrations of the four phenolic compounds. The percentage of germination of wheat significantly decreased with increasing of ferulic acid reaching a maximum inhibition at 3.0 mM concentration. On the other hand, the germination of wheat was not affected with the other three phenolic compounds. The percentage of germination of barley was not affected with all phenolic compounds except for hydroxy phenolic acetic acid which has significant effect at a concentration of 3.0 mM. Salicylic acid significantly inhibited the growth parameters gradually in wild oat, wheat and barley. The shoot/root ratio was decreased in wild oat and barley, while the ratio increased in wheat. The growth parameters were completely inhibited at 3.0 mM of ferulic acid for both wild oat and wheat but slightly inhibited for barley. The shoot/root ratio was increased in all concentrations of ferulic acid except at 3.0 mM which was completely inhibited for both wild oat and wheat, while the ratio was increased in all treatments of ferulic acid in the case of barley. The growth parameters were highly significant and decreased in wild oat, wheat and barley with increasing the concentrations of hydroxybenzoic acid and hydroxyphenyl acetic acid. The shoot/root ratio was not changed in all concentrations except at 3.0 mM in the case of wild oat, the ratio was decreased at 2.0 and 3.0 mM in the case of wheat, while the ratio increased in most

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of hydroxybenzoic acid concentrations in the case of barley. The shoot/root ratio was increased with increasing of the hydroxyphenyl acetic acid concentrations.

1. Introduction

Weeds are one of the major problems in crop production. They compete with crop plants for light, moisture, nutrients and space. *Avena fatua* L. (wild oat) is considered the 13th most important weed worldwide (Holm et al., 1977). *A. fatua* has increased tremendously in the rain fields and irrigated areas of the country as well as elsewhere in the world. It is an annual grass and is difficult to eradicate because the seeds shatter before crop maturation and many of the seeds are plowed into the soil, when they are turned up near the surface. Walia et al. (1998) concluded that wheat yield decreased exponentially when wild oat populations varied from 0 to 100 plants m^{-2} and the loss approached 50–60% at 100 plants of wild oats m^{-2}. High seeding rates of wheat also reduced the impacts of weed on crops in a number of previous studies (Lajos et al., 2000; Hassan, 2006; Khan et al., 2007).

The time of weed germination and emergence in the field is influenced by environmental factors, such as light, soil temperature, soil moisture and soil atmosphere (Forcella et al., 2000). *A. fatua* seedlings can exceed the crop wheat, barley, and rye in its ability to emerge at greater depths in the soil. It has allelopathic phenolic compounds, which impact other plants, inhibiting germination and seedling growth (Sharma and Van den Born, 1978). Yield loss due to weed competition in the wheat fields has been reported to be about 21%. Approximately 79% of wheat (*Triticum aestivum* L.) and 72% of barley (*Hordium vulgare* L.) hectares seeded in northwestern Minnesota are infected with wild oat (Dexter et al., 1981).

The ability to predict the time of seedling emergence is an important step toward increasing the timeliness and efficiency of chemical and cultural weed control measures (Forcella et al., 1993). Because the intensity of crop–weed competition is affected by the timing of weed emergence relative to the crop phonological development (Conley et al., 2003), timely weed control is used as a key component to maximizing crop yield potential. Controlling weed seedlings that emerge early may help to reduce the competition during the critical phases of crop seedling establishment (Black and Dyson, 1997).

It was found that weed seedlings effectively competes for light by growing to greater heights than the wheat crop (Cudney et al., 1991). Over the last three decades wheat production in many parts of the world has relied heavily on herbicides as the primary method of weed management (Montazeri et al., 2005).

A major consideration when using herbicides is the sensitivity and hazard to other non-target species and organisms in the area (Callihan et al., 1995). Improper application and/or application rates can harm many other species, along with affecting water quality, the eventual accumulation of these compounds in underground and aboveground water bodies (Callihan et al., 1995). But environmental safety concerns, increasing occurrence of herbicide resistance in weed species and the need to reduce input costs have caused a growing awareness that intensive use of chemical weed control does not fit well in sustainable agriculture systems (Gealy et al., 2003). Another method for entirely eliminating weeds from the crop environment is the use of phenolic compounds which will be an acceptable method of weed control. The objectives of this study were: (1) to determine the influence of the using phenolic compounds on *A. fatua* weed control in germination and early growth stage, (2) to determine the effect of using phenolic compounds in germination and early growth stage of wheat (*T. aestivum*) and barley (*H. vulgare*).

In this study, control of wild oat was achieved by the application of some phenolic compounds including salicylic acid, ferulic acid, hydroxybenzoic acid and hydroxyphenyl acetic acid. The effect of these compounds on the germination and growth parameters of wheat and barley was also studied.

2. Material and methods

2.1. Plant materials

A. fatua: (wild oat), *T. aestivum* (wheat) cv. Sakha61, and *H. vulgare* (barely) cv. Giza129 grains were obtained from Agricultural Research Center, Giza, Egypt.

2.2. Chemicals

Salicylic acid, ferulic acid, hydroxybenzoic acid and hydroxyphenyl acetic acid were obtained from Aldrich Co.

2.3. Germination experiment

Different concentrations were used (0.0, 0.05, 0.2, 0.7, 1.0, 2.0 and 3.0 mM) for all germination test experiments. Sterilized Petri dishes (9.0 cm) lined with double layers of Whattman No. 1 filter papers were used for every treatment, three replicates were taken, each consisting of 20 grains. The filter papers were watered as needed by adding 5 ml of distilled water (for control) or solutions to be tested. Petri dishes were incubated at temperatures of 17 ± 2 °C.

2.4. Growth parameters

As a germination experiment, different concentrations of phenolic compounds were used. Root length, shoot length, plant length, and number of roots were measured in germinating seedlings for the four phenolic compounds in all treatments. Three replicates were taken and the mean was calculated.

2.5. Statistical analysis

All the results are an average of at least three replicates. The data were analyzed by the one-way ANOVA followed by Tukey–Kramer's multiple comparison tests ($p \geqslant 0.05$) (SPSS, 1999).

3. Results and discussion

The results in Table 1 showed that wild oat was highly affected with the different treatments of the four phenolic compounds

Table 1 Effect of different concentrations (mM) of the four phenolic compounds (salicylic acid, ferulic acid, hydroxy benzoic acid and hydroxy phenyl acetic acid) on the percentage of germination of *A. fatua*, *T. aestivum* and *H. vulgare*.

Treatment (mM)	Salicylic acid			Ferulic acid			Hydroxy benzoic acid			Hydroxy phenyl acetic acid		
	A. fatua	*T. aestivum*	*H. vulgare*	*A. fatua*	*T. aestivum*	*H. vulgare*	*A. fatua*	*T. aestivum*	*H. vulgare*	*A. fatua*	*T. aestivum*	*H. vulgare*
0.0	65.0 ± 7.1	100.0 ± 0.0	100.0 ± 0.0	72.5 ± 3.5	100.0 ± 0.0	100.0 ± 0.00	67.5 ± 1.7	100.0 ± 0.0	100.0 ± 0.0	72.5 ± 3.5	100.0 ± 0.0	100.0 ± 0.0
0.05	52.5 ± 10.6**	100.0 ± 0.0**	100.0 ± 0.0**	67.5 ± 10.6	100.0 ± 0.0	100.0 ± 0.0**	82.5 ± 3.5	100.0 ± 0.0**	100.0 ± 0.0**	75.0 ± 7.1	100.0 ± 0.0**	100.0 ± 0.0
0.2	62.5 ± 3.5	100.0 ± 0.0**	100.0 ± 0.0**	27.5 ± 3.2**	100.0 ± 0.0	100.0 ± 0.0**	72.5 ± 1.6	100.0 ± 0.0**	100.0 ± 0.0**	62.5 ± 3.5	100.0 ± 0.0**	100.0 ± 0.0
0.7	57.5 ± 10.6	100.0 ± 0.0**	100.0 ± 0.0**	17.5 ± 1.1**	100.0 ± 0.0	100.0 ± 0.0**	60.0 ± 0.0	100.0 ± 0.0**	100.0 ± 0.0**	45.0 ± 0.0**	100.0 ± 0.0**	100.0 ± 0.0
1.0	57.5 ± 3.5	100.0 ± 0.0**a	100.0 ± 0.0**	15.0 ± 2.1**	100.0 ± 0.0	100.0 ± 0.0**	22.5 ± 3.5a	100.0 ± 0.0**	100.0 ± 0.0**	40.0 ± 0.0**	100.0 ± 0.0**	100.0 ± 0.0
2.0	47.5 ± 31.8**	100.0 ± 0.0**	100.0 ± 0.0**	7.5 ± 1.6**	50.0 ± 4.2**	100.0 ± 0.0**	20.0 ± 0.0a	100.0 ± 0.0**	100.0 ± 0.0**	15.0 ± 1.4**	100.0 ± 0.0**	100.0 ± 0.0
3.0	40.0 ± 21.2**	100.0 ± 0.0**	100.0 ± 0.0**	0.0 ± 0.0**	0.0 ± 0.0**	100.0 ± 0.0**	7.5 ± 1.6a	100.0 ± 0.0**	100.0 ± 0.0**	2.5 ± 3.5**	100.0 ± 0.0**	47.5 ± 3.5**
LSD												
1%	11.5	0.0	0.0	24.2	31.6	0.0	23.5	0.0	0.0	21.7	0.0	15.1
5%	8.3	0.0	0.0	17.4	22.7	0.0	16.8	0.0	0.0	15.6	0.0	11.0

*Significant at 5%.
** Highly significant at 1%.

(salicylic acid, ferulic acid, hydroxyl benzoic acid and hydroxy phenyl acetic acid). The percentage of germination of wild oat was significantly inhibited with increasing the concentrations of phenolic compounds. Ferulic acid was the most effective compound which completely inhibited the germination at a concentration of 3.0 mM. At the same time, wheat and barley were slightly affected with the different concentrations of the four phenolic compounds. The percentage of germination of wheat was significantly decreased with increasing the ferulic acid reaching to maximum inhibition at 3.0 mM concentration. On the other hand, the germination of wheat was not affected with the other three phenolic compounds. The percentage of germination of barley was not affected with all phenolic compounds except for hydroxy phenolic acetic acid which has a significant effect at a concentration of 3.0 mM. From the above we can conclude that salicylic acid and hydroxy benzoic acid has no effect on the percent of germination of both wheat and barley, at the same time, these two phenolic compounds have adverse effect on wild oat, so it is recommended that these two compounds were used to control this weed.

Phenolic acids (caffeic, ferulic and cinnamic acids), phenolic substances, such as polyphenols tannins, flavonols (quercetin) in the fruit and seed inhibit germination (Baskin and Baskin, 1998). The inhibitory effects of the phenolic compound on seed germination are closely related with the regulation of endogenous auxin, seed coat permeability and oxygen supply to the embryos (Bewley and Black, 1994).

Inhibition of weed germination and seedling growth by small grain residues in no-till systems may be due to: (i) the physical barriers and shading associated with the residue and reduced soil disturbance (Worsham, 1989), and (or) (ii) allelopathic compounds (Barnes et al., 1986; Shilling et al., 1985, 1986a,b; Waller et al., 1987). Although the relative significance of each of these factors for weed control in no-till systems is unclear considerable emphasis has been placed on characterizing the role of allelopathic interactions in such systems. Potential allelopathic compounds identified in living and decomposing tissue of small grain-cover crops including phenolic acids (Barnes et al., 1986; Blum et al., 1991), hydroxamic acids (Gaglirdo and Chilton, 1992; Nair et al., 1990; Niemeyer et al., 1989), other organic acids (Shilling et al., 1985; Tang and Waiss, 1978) and volatile substances (Bradow, 1991; Buttery et al., 1985). Among these, phenolic acids have been most frequently identified as phytotoxins. A major concern regarding the role of phenolic acids as allelopathic agents in no-till systems pertains to the fact that the concentrations of individual phenolic acids recoverable from field soils are well below the levels required for inhibition of germination and growth *in vitro* (Blum et al., 1989, 1991, 1993; Lyu et al., 1990; Waller et al., 1987).

It is well known that the crop residues left in the soil are sometimes harmful to plant growth. The plant residues in soil could release phytotoxic substances during decomposition period.

The results in Table 2 revealed that salicylic acid has an adverse effect on the growth parameters which significantly inhibited the shoot and root lengths till they gradually reached to nearly 75% for wild oat, while they reached up to 50% for wheat and about 25% for barley at 3.0 mM salicylic acid concentration. The shoot/root ratio was decreased to a high rate in wild oat and no detected decrease in barley was seen while the

Table 2 Effect of different concentrations of salicylic acid (mM) on the growth parameters of *A. fatua*, *T. aestivum* and *H. vulgare*.

Treatment (mM)	*Avena fatua*					*Triticum aestivum*					*Hordium vulgare*				
	Shoot length (mm)	Root length (mm)	Plant length (mm)	S/R	No. roots	Shoot length (mm)	Root length (mm)	Plant length (mm)	S/R	No. roots	Shoot length (mm)	Root length (mm)	Plant length (mm)	S/R	No. roots
0.0	10.8 ± 0.4	10.5 ± 0.7	21.3 ± 1.1	1.02	4.5 ± 0.7	14.5 ± 0.7	15.5 ± 0.7	30.0 ± 0.0	0.94	4.5 ± 0.7	13.0 ± 0.0	14.0 ± 0.0	27.0 ± 0.0	0.93	5.0 ± 0.0
0.05	7.5 ± 0.7**	11.5 ± 0.7	19.0 ± 1.4	0.64	3.0 ± 0.0**	12.3 ± 0.4*	11.5 ± 0.7**	23.8 ± 0.4**	1.07	3.0 ± 0.0**	12.3 ± 0.4**	16.5 ± 0.7	28.8 ± 1.1	0.74	4.0 ± 0.0**
0.2	6.0 ± 0.0**	8.5 ± 0.7**	14.5 ± 0.7**	0.71	3.0 ± 0.0**	11.3 ± 0.4**	10.5 ± 0.7**	21.8 ± 1.1**	1.1	3.0 ± 0.0**	11.5 ± 0.7**	16.5 ± 0.7	28.0 ± 0.0	0.69	4.0 ± 0.0**
0.7	6.0 ± 1.4**	7.5 ± 0.7**	13.5 ± 2.1**	0.8	3.0 ± 0.0**	8.8 ± 0.4**	9.5 ± 0.7**	18.3 ± 1.1**	0.93	2.5 ± 0.7**	10.5 ± 0.7**	5.5 ± 0.7**	16.0 ± 1.4**	1.9	3.0 ± 0.0**
1.0	5.3 ± 0.4**	6.5 ± 0.7**	11.8 ± 0.7**	0.81	3.0 ± 0.0**	7.8 ± 0.4**	8.5 ± 0.7**	16.3 ± 1.1**	0.92	2.5 ± 0.7**	9.8 ± 0.35**	7.5 ± 0.7**	17.3 ± 1.1**	1.3	3.0 ± 0.0**
2.0	3.8 ± 0.4**	5.5 ± 0.7**	9.3 ± 1.4**	0.68	2.5 ± 0.7**	7.0 ± 0.0**	5.8 ± 1.1**	12.8 ± 1.1**	1.2	2.0 ± 0.0**	9.5 ± 0.7**	9.0 ± 1.4**	18.5 ± 2.1**	1.1	3.5 ± 0.7**
3.0	2.3 ± 0.4**	3.5 ± 0.7**	5.8 ± 0.4**	0.64	2.5 ± 0.7**	6.5 ± 0.7**	4.5 ± 0.7**	11.0 ± 0.0**	1.4	2.5 ± 0.7**	8.8 ± 0.4**	9.0 ± 2.8**	17.8 ± 3.2**	0.97	3.0 ± 0.0**
LSD															
1%	2.13	2.19	4.2	–	0.57	2.32	2.85	5.1	–	0.69	1.23	3.5	4.5	–	0.59
5%	1.53	1.58	3.04	–	0.41	1.66	2.05	3.7	–	4.09	0.88	2.5	3.2	–	0.43

* Significant at 5%.
** Highly significant at 1%.

Table 3 Effect of different concentrations of ferulic acid (mM) on the growth parameters *A. fatua*, *T. aestivum* and *H. vulgare*.

Treatment (mM)	*Avena fatua*					*Triticum aestivum*					*Hordium vulgare*				
	Shoot length (mm)	Root length (mm)	Plant length (mm)	S/R	No. roots	Shoot length (mm)	Root length (mm)	Plant length (mm)	S/R	No. roots	Shoot length (mm)	Root length (mm)	Plant length (mm)	S/R	No. roots
0.0	4.5 ± 0.7	10.7 ± 0.9	15.2 ± 1.4	0.4	10.5 ± 0.7	5.0 ± 0.0	16.5 ± 0.7	21.5 ± 0.7	0.3	15.0 ± 0.0	4.5 ± 0.7	13.5 ± 0.7	18.0 ± 0.0	0.3	13.0 ± 0.0
0.05	8.8 ± 0.4**	10.5 ± 0.7	19.3 ± 1.1*	0.8	3.0 ± 0.0**	10.5 ± 0.7**	13.5 ± 0.7*	24.0 ± 1.4	0.8	5.0 ± 0.0**	9.3 ± 0.4**	10.5 ± 0.7**	19.8 ± 0.4*	0.9	4.5 ± 0.7**
0.2	1.5 ± 0.7**	1.5 ± 0.7**	3.0 ± 0.0**	1.0	1.0 ± 0.0**	7.5 ± 0.7**	11.5 ± 0.7*	19.0 ± 0.0	0.7	4.5 ± 0.7**	8.5 ± 0.7**	9.5 ± 0.7**	18.0 ± 0.0	0.9	3.5 ± 0.7**
0.7	1.3 ± 0.4**	2.0 ± 0.0**	3.3 ± 0.4**	0.7	2.0 ± 0.0**	7.5 ± 0.7**	11.0 ± 0.4**	18.5 ± 0.7	0.7	5.0 ± 0.0**	8.5 ± 0.7**	6.5 ± 0.7**	15.0 ± 1.4**	1.3	4.5 ± 0.7**
1.0	0.8 ± 0.1**	0.5 ± 0.07**	1.3 ± 0.2**	1.6	1.0 ± 0.1**	6.5 ± 0.7	9.5 ± 0.7**	16.0 ± 1.4*	0.7	5.0 ± 0.0**	6.0 ± 0.0**	7.3 ± 0.4**	13.3 ± 0.4**	0.8	4.0 ± 0.0**
2.0	1.0 ± 0.1**	0.5 ± 0.07**	1.5 ± 0.2**	2.0	0.5 ± 0.07**	3.3 ± 0.4*	2.7 ± 0.4**	6.0 ± 0.7**	1.2	6.0 ± 0.0**	5.8 ± 0.4*	6.8 ± 0.4**	12.6 ± 0.7**	0.9	3.5 ± 0.7**
3.0	0.0 ± 0.0**	0.0 ± 0.0**	0.0 ± 0.0**	0.0	0.0 ± 0.0**	0.0 ± 0.0**	0.0 ± 0.0**	0.0 ± 0.0**	0.0	0.0 ± 0.0**	4.8 ± 0.4	6.3 ± 0.4**	11.1 ± 0.7**	0.8	4.0 ± 0.0**
LSD															
1%	2.4	3.6	5.7	–	2.7	2.4	4.5	6.6	–	3.3	1.5	2.1	2.5	–	2.6
5%	1.7	2.6	4.1	–	1.9	1.7	3.2	4.8	–	2.4	1.1	1.5	1.8	–	1.9

* Significant at 5%.
** Highly significant at 1%.

Table 4 Effect of different concentrations of hydroxy benzoic acid (mM) on the growth parameters of *A. fatua*, *T. aestivum* and *H. vulgare*.

Treatment (mM)	*Avena fatua*					*Triticum aestivum*					*Hordium vulgare*				
	Shoot length (mm)	Root length (mm)	Plant length (mm)	S/R	No. roots	Shoot length (mm)	Root length (mm)	Plant length (mm)	S/R	No. roots	Shoot length (mm)	Root length (mm)	Plant length (mm)	S/R	No. roots
0.0	10.3 ± 0.4	12.3 ± 0.4	22.6 ± 0.0	0.8	4.5 ± 0.7	14.3 ± 0.4	16.5 ± 0.7	30.8 ± 0.4	0.9	4.5 ± 0.7	13.5 ± 0.7	13.5 ± 0.7	27.0 ± 1.4	1.0	5.0 ± 0.0
0.05	10.0 ± 0.0	14.0 ± 0.7	24.0 ± 0.4	0.7	3.5 ± 0.7**	13.3 ± 0.4	14.5 ± 0.7	27.8 ± 1.1	0.9	5.0 ± 0.0*	11.5 ± 0.7*	11.5 ± 0.7	23.0 ± 0.0*	1.0	5.0 ± 0.0
0.2	9.3 ± 0.4	13.0 ± 0.0	22.3 ± 0.4	0.7	3.5 ± 0.7**	8.5 ± 0.7**	8.5 ± 0.7**	17.0 ± 1.4**	1.0	3.5 ± 0.7**	8.5 ± 0.7**	10.5 ± 0.7*	19.0 ± 0.0**	0.8	3.5 ± 0.7**
0.7	8.5 ± 0.7	10.5 ± 0.7	19.0 ± 0.0	0.8	4.0 ± 0.0**	7.5 ± 0.7**	7.0 ± 0.0**	14.5 ± 0.7**	1.1	3.5 ± 0.7**	10.3 ± 0.4**	9.5 ± 0.7**	19.8 ± 1.1**	1.1	4.5 ± 0.7*
1.0	4.5 ± 0.7**	6.7 ± 0.9**	11.2 ± 1.6**	0.7	3.0 ± 0.0**	6.5 ± 0.7**	5.5 ± 0.7**	12.0 ± 0.0**	1.2	4.0 ± 0.0**	8.3 ± 0.4**	9.5 ± 0.7**	17.8 ± 1.1**	0.9	4.0 ± 0.0**
2.0	2.3 ± 0.4**	3.5 ± 0.0**	5.8 ± 0.4**	0.7	3.0 ± 0.0**	2.8 ± 0.4**	4.0 ± 0.0**	6.8 ± 0.4**	0.7	3.0 ± 0.0**	6.3 ± 0.4**	3.8 ± 0.4**	10.0 ± 0.0**	1.7	3.5 ± 0.7**
3.0	1.3 ± 0.4**	3.3 ± 0.4**	4.6 ± 0.7**	0.4	3.0 ± 0.0**	1.8 ± 0.4**	3.5 ± 0.7**	5.3 ± 1.1**	0.5	3.0 ± 0.0**	3.3 ± 0.4**	2.8 ± 0.4**	6.0 ± 0.0**	1.2	3.0 ± 0.0**
LSD															
1%	2.9	3.5	6.4	–	0.5	3.7	3.9	7.5	–	0.6	2.6	3.1	5.6	–	0.7
5%	2.1	2.5	4.6	–	0.4	2.6	2.8	5.4	–	0.4	1.9	2.2	4.0	–	0.5

* Significant at 5%.
** Highly significant at 1%.

Table 5 Effect of different concentrations of hydroxy phenyl acetic acid (mM) on the growth parameters of *A. fatua*, *T. aestivum* and *H. vulgare*.

Treatment (mM)	*Avena fatua* Shoot length (mm)	Root length (mm)	Plant length (mm)	S/R	No. roots	*Triticum aestivum* Shoot length (mm)	Root length (mm)	Plant length (mm)	S/R	No. roots	*Hordium vulgare* Shoot length (mm)	Root length (mm)	Plant length (mm)	S/R	No. roots
0.0	11.5 ± 0.7	10.5 ± 0.7	22.0 ± 1.4	1.1	4.5 ± 0.7	16.5 ± 0.7	14.5 ± 0.7	31.0 ± 1.4	1.1	4.0 ± 0.0	14.0 ± 0.0	13.0 ± 0.0	27.0 ± 0.0	1.1	5.0 ± 0.0
0.05	12.8 ± 0.4	15.5 ± 0.7**	28.3 ± 1.1*	0.8	4.0 ± 0.0	13.5 ± 0.7*	13.5 ± 0.7	27.0 ± 1.4	1.0	4.0 ± 0.0	14.8 ± 0.4	14.5 ± 0.7*	29.3 ± 1.1	1.0	5.0 ± 0.0
0.2	10.5 ± 0.7	12.0 ± 0.0	22.5 ± 0.7	0.9	3.5 ± 0.7**	11.8 ± 0.4**	10.5 ± 0.7**	22.3 ± 1.1**	1.1	4.0 ± 0.0	12.8 ± 0.4**	12.5 ± 0.7	25.3 ± 1.4	1.0	5.0 ± 0.0
0.7	9.0 ± 0.0*	9.3 ± 0.4	18.3 ± 0.4	1.0	3.0 ± 0.0**	10.5 ± 0.7**	8.8 ± 0.4**	19.3 ± 1.1**	1.2	3.5 ± 0.7*	11.3 ± 0.4**	10.5 ± 0.7**	21.8 ± 0.4**	1.1	4.0 ± 0.0**
1.0	7.0 ± 0.0**	4.5 ± 0.7**	11.5 ± 0.7**	1.6	3.5 ± 0.7**	8.4 ± 0.8**	7.5 ± 0.7**	15.9 ± 1.6**	1.1	3.0 ± 0.0**	12.5 ± 0.7**	10.5 ± 0.7**	23.0 ± 1.4**	1.2	3.5 ± 0.7**
2.0	4.5 ± 0.7**	1.8 ± 0.4**	6.3 ± 1.1**	2.5	3.0 ± 0.0**	5.8 ± 0.4**	2.5 ± 0.7**	8.3 ± 1.1**	2.3	2.5 ± 0.7**	11.3 ± 0.4**	10.8 ± 0.4**	22.1 ± 0.0**	1.1	3.0 ± 0.0**
3.0	1.8 ± 0.4**	0.8 ± 0.4**	2.6 ± 0.7**	2.3	1.5 ± 0.7**	3.3 ± 0.4**	2.0 ± 0.0**	5.3 ± 0.4**	1.7	2.0 ± 0.0**	8.5 ± 0.7**	7.5 ± 0.7**	16.0 ± 1.4**	1.1	3.5 ± 0.7**
LSD															
1%	3.1	4.2	7.3	–	0.8	3.5	3.8	7.3	–	0.7	1.6	1.8	3.3	–	0.7
5%	2.2	3.0	5.2	–	0.6	2.5	2.7	5.2	–	0.5	1.2	1.3	2.4	–	0.5

* Significant at 5%.
** Highly significant at 1%.

ratio increased in wheat when salicylic acid concentrations increased.

The results in Table 3 showed that the growth parameters were completely inhibited at 3.0 mM of ferulic acid for both wild oat and wheat but slightly inhibited for barley. The shoot/root ratio was increased in all concentrations of ferulic acid except at 3.0 mM which was completely inhibited for both wild oat and wheat, while the ratio was increased in all treatments of ferulic acid in the case of barley.

The results in Table 4 showed that the growth parameters were highly significantly decreased in wild oat, wheat and barley with increasing concentrations of hydroxybenzoic acid. The shoot/root ratio was not changed at all concentrations except at 3.0 mM where the ratio dropped to 50% in the case of wild oat, the ratio was increased till the concentration reached 1.0 mM and then decreased at 2.0 and 3.0 mM in the case of wheat, while in general the ratio increased in most of the hydroxybenzoic acid concentrations in the case of barley.

The results in Table 5 showed that the growth parameters were significantly decreased in wild oat, wheat and barley with increasing the concentrations of hydroxyphenyl acetic acid. The shoot/root ratio was increased by increasing the hydroxyphenyl acetic acid concentrations.

Salicylic acid (SA) and related compounds have been reported to induce significant effects in various biological aspects in plants. These compounds influence in a variable manner; inhibiting certain processes and enhancing the others (Raskin, 1992).

Phenolic compounds and flavonoids are among the most influential and widely distributed secondary products in the plant kingdom. Many of them play important physiological and ecological roles, being involved in resistance to different types of stress (Delalonde et al., 1996; Rice-Evans and Miller, 1998; Ayaz et al., 2000).

Allelopathy is a mechanism of plant interference in agroecosystems that offers an opportunity to manage weeds in crop sequence but could also adversely affect crop yields and influence the choice of rotation. The allelopathic potential of many crop plants has been investigated and approved (Burgos et al., 1999; Baghestani et al., 1999; Wu et al., 2001). Heavy use of herbicides in most integrated weed management (IWM) systems is a major concern since it causes serious threats to the environment, public health and increases the costs of crop production. The degree of weed seed germination inhibition and growth suppression which can be attributed to crop allelopathy is highly important and worthwhile. This can be considered as a possible alternative to weed management strategy (Macias, 1995).

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