Australian Journal of Crop Science AJCS
AJCS 5(11):1434-1440 (2011) ISSN:1835-2707

Allelopathic potential of sunflower on weed management in safflower and wheat

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Abstract

Allelochemicals have the potential to create friendly-eco products for weed management. Because synthetic herbicides pose worldwide risks to health and the environment, the need for alternative methods for weed control has become acute. This study evaluated the allelopatic potential of different sunflower cultivars on several crops and associated weeds at different concentrations. Factorial experiments were performed based on a completely randomized block design with three replications. The first factor included eight sunflower cultivars. The second factor was the concentration of the extracts (25, 50 and 100%). The third factor was the type of target plant (*Amaranthus retroflexus*, *Portulaca oleracea*, *Lolium rigidum, Hordeum spontaneum*, wheat and safflower). The results showed that *Amaranthus retroflexus* was the most sensitive to sunflower allelopathy, and *P. oleracea* was the most resistant. As extract concentration increased from 25 to 100%, the inhibitory effect on germination indices increased, while with 25% extract concentration was observed to have stimulating effects on wheat and *Portulaca oleracea* germination. The Megasun sunflower cultivar had the most effect and Hysun36 had the least effect on the target plants. Megasun extract at 100% concentration effectively suppressed over 80% of selected weeds. The results indicate that the allelopathic properties of some sunflower cultivars can affect noxious weed species such as *H. spontaneum* and *L. rigidum* in wheat and *A. retroflexus* in safflower.

Keywords: bioassay, water extract, allelochemicals, germination indices.
Abbreviation: IP inhibition percentage, MGT Mean germination time

Introduction

Allelopathy has been defined as the inhibitory or stimulatory effects of a plant or microorganism on other plants through the release of chemical compounds into the environment. Most allelochemicals are classified as secondary metabolites of the plant (Kruse et al., 2000). It is well documented that the production of secondary metabolites is characterized by the plant's genetic and environmental conditions during its growth (Quader et al., 2001). However, these stimulatory and inhibitory effects depend on the concentration of the compounds (Bhowmik and Inderjiit, 2003). The widespread use of herbicides has resulted in the increasing incidence of weeds' resistance to them, and in environmental pollution and associated health problems (Macias et al., 1998). Allelopathy is a natural technique that may be considered as a tool for biological weed control and in crop production (Cheema and Khaliq, 2000: Heidarzadeh et al., 2010). Allelochemicals may be used to develop new tools to combat the evolution of herbicide resistance in weeds (Anjum and Bajwa, 2005). Future weed control might consist of multiple integrated strategies, of which one might be making crops suppress weeds themselves by improved allelopathy and competition (Belz, 2007).

When susceptible plants are exposed to allelochemicals, germination, growth and development may be affected (Xuan et al., 2004). The most frequent reported gross morphological effects on plants are inhibited or retarded seed germination and effects on coleoptile elongation and shoot and root development (Kruse et al., 2000). It has been reported that some plants have allelopathic potential to reduce emergence: examples include *Medicago polymorpha* (Anjum and Bajwa, 2005), *Oryza sativa* L. (Xuan et al., 2005), *Sorghum bicolor* (Cheema and Khaliq, 2000), *Chenopodium album*, *Amaranthus retroflexus* and *Cynodon dactylon* (Rezaie and Yarnia, 2009). Allelochemicals that suppress or eliminate plant species have received special attention due to the agricultural potential of these compounds as selective natural herbicides (Vyvyan, 2002). Allelopathic crops offer strong potential for the development of cultivars that are more highly weed-suppressive (Weston and Duke, 2003). The allelopathic properties of sunflowers are well-recognized; their effects on many weeds and crops have been documented. Macias et al. (2002) isolated 125 natural allelopathic compounds that are phytotoxic towards many plants from different sunflower cultivars. Sunflower extracts completely inhibited seed germination of white mustard (*Sinapis alba* L.) (Bogatek et al., 2006. Kupidlowska et al., 2006) , although sunflower phytotoxins did not affect seed viability (Kupidlowska et al., 2006). An annuionone isolated from aqueous extract of sunflower (cv. Suncross-42 leaves), (Anjum and Bajwa, 2005) reduced the growth of all five selected weed species: *Phalaris minor* Retz., *Chenopodium album* L., *Coronopis didymus* (L.), *Medicago. polymorpha* L. and *Rumex dentatus* L. Heliannuols, terpenoids and flavonoids are the most important allelopathic compounds isolated from sunflowers (Vyvyan, 2002). Allelopathic material from sunflowers can influence the antioxidant systems in target plants, causing cell-membrane permeability and cellular damage, reducing the target plants' ability to germinate and causing a gradual loss of seed vigor (Oracz et al., 2007). It seems that the negative effects of sunflower

Table 1. Analysis of Variance of Three Different Concentrations of Allelopathic Extracts of Eight Different Sunflower Cultivars on Germination Indices of Six Target Plant Species

Source	DF	Mean square				
		Germination (%)	Germination rate	Root length (mm)	Shoot height (mm)	Seedling weight (g)
Target plant	5	80396.04**	70918.01**	44409.84**	25403.45**	98039.67**
Sunflower cultivar	7	2505.54**	2371.94**	15654.69**	12386.63**	10670.81**
Extract concentration	2	42598.76**	76967.87**	168076.3**	135895.26**	80136.34**
Plant × cultivar	35	896.03**	485.08**	18719.92**	2889.44**	1415.16**
Plant × concentration	10	3811.61**	6248.8**	4316.2**	5881.28**	3718.97**
Cultivar × concentration	14	581.18**	358.53**	6076.01**	913.22**	1862.51**
Plant × cultivar × Concentration	70	522.62**	361.4**	3797.28**	1328.54**	1389.86**
Error	288	116.93	84.26	304.06	173.64	437.47

*, ** indicate significance at 5% and 1% level, respectively

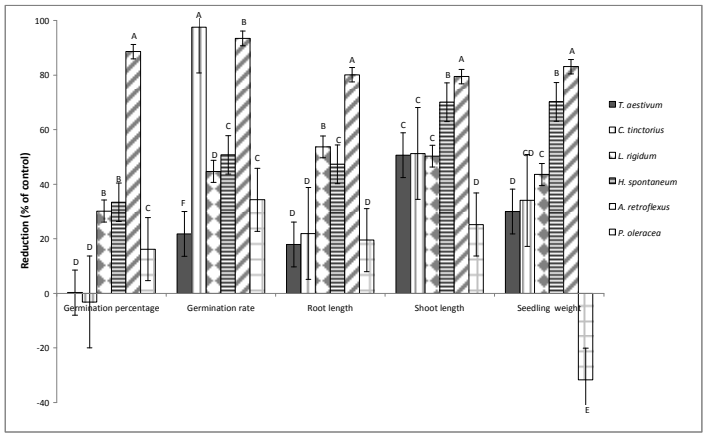

Fig 1. Effect of sunflower allelochemical extract on germination indices of target plants. Columns with the same letter at the top are not significantly different (P < 0.05); error bars represent standard error.

extracts are not due to osmotic potential, but to their toxic effects. Analysis of polyunsaturated fatty acids in target plants' cell membranes has revealed severe damage to membranes and damage to the fat sources stored in the seed (Oracz et al., 2007). Ultimately, isolating chemicals from plants and conducting bioassays is not enough to confirm allelopathic effects. However, these sorts of laboratory experiments for allelopathy are quick and repeatable, and help demonstrate the potential for allelochemical interactions (Inderjit and Weston, 2000; Inderjit and Callaway, 2003). The present study was, therefore, carried out to evaluate the herbicidal potential of sunflower-cultivar leaf extracts against two broad-leaf weeds, two narrow-leaf weeds and two crops under bioassay laboratory conditions.

Results and Discussion

Analysis of variance showed that the main effects and interaction for all germination indices were significant (Table 1). *A. retroflexus* was the most sensitive plant to sunflower allelopathy (Figure 1). The inhibitory effect of *Plantago psyllium* and saffron (*Crocus sativus*) on all indices of *A. retroflexus* germination has been reported (Rahimi et al., 2006; Rashed et al., 2009). Also, Yarnia et al. (2009) suggested that *A. retroflexus* populations can be reduced by allelopathic extracts prepared from different parts of the sorghum plant, as the growth and germination of *A. retroflexus* were reduced by 50 to 60%. Our findings also indicated that *H. sponatneum* is the second-most sensitive weed to sunflower allelopathy (Figure 1). *H. sponatneum* is a problematic weed in wheat crops in Iran and elsewhere, and normally uncontrollable by herbicides (Zand et al., 2007); thus, possible biological controls for it may be of great importance. The results also indicated that *L. rigidum* is sensitive to extracts of sunflower cultivars, as sunflower extract reduced all traits in this weed (Figure 1). Although there have been many reports of herbicide resistance for this weed worldwide (Walsh and Powles, 2007), it may be possible to control it by sunflower allelopathy. Among tested plants, *P. oleracea* showed the least sensitivity to sunflower extracts (Figure 1). The extracts of some cultivars reduced some germination indices of *P. oleracea*, suggesting that some cultivars may be effective in its control, while others not only had no negative effects but actually stimulated the growth of some traits (Table 2). For example, Megasun reduced the root length of *P. oleracea* by 79%, while Alison caused a 39% increase in root length (Table 2). It is reported that *P. oleracea* is one of the most resistant weeds to herbicides (Zhang et al., 1997). Our results showed that it is also resistant to allelochemicals. It is thought that the impenetrability of its hard-shell seeds is the main cause of its resistance to chemicals (Egley, 1986), although two phenolic acids have been identified in *P. oleracea* that may contribute to its resistance to synthetic and bio-herbicides (Oliveira et al., 2009). Wheat and safflower showed high levels of tolerance to sunflower allelopathy; in fact, sunflower

Table 2. Interaction Effects of Target Plants and Allelopathic Sunflower Cultivars on the Inhibition Percentage of Target Plants' Germination Indices

Target plant	Sunflower cultivars	Germination percentage inhibition (%)	Germination rate inhibition (%)	Root length inhibition (%)	Shoot height inhibition (%)	Seedling weight inhibition (%)
L. rigidum	Alison	44.7±(7.3)	65.0±(6.1)	73.0±(8.2)	65.3±(5.9)	55.6±(6.1)
L. rigidum	Blazar	13.9±(6.5)	31.2±(1.2)	16.8±(5.2)	56.5±(2.7)	42.3±(3.4)
L. rigidum	Hysun25	17.5±(2.0)	46.4±(6.8)	30.2±(1.7)	28.7±(1.7)	26.3±(3.6)
L. rigidum	Hysun36	10.4±(3.8)	29.0±(5.4)	-0.1±(0.3)	14.2±(5.6)	2.9±(1.8)
L. rigidum	Megasun	37.4±(11.4)	45.8±(1.8)	74.5±(8.5)	56.2±(1.0)	55.9±(1.5)
L. rigidum	Urfloar	26.8±(1.1)	34.5±(1.8)	66.8±(7.9)	67.2±(6.7)	53.5±(9.2)
L. rigidum	Allstar	40.8±(11.1)	48.7±(1.5)	81.2±(5.7)	53.9±(1.1)	52.2±(1.6)
L. rigidum	Hysun33	49.8±(9.8)	57.0±(9.7)	87.2±(4.5)	60.1±(0.4)	59.7±(8.1)
H. spontaneum	Alison	20.3±(1.9)	43.8±(11.0)	43.0±(1.3)	76.6±(10.3)	73.6±(9.2)
H. spontaneum	Blazar	17.1±(1.5)	40.1±(2.6)	13.0±(3.9)	49.9±(2.7)	47.9±(9.0)
H. spontaneum	Hysun25	25.7±(1.4)	42.5±(9.7)	54.5±(1.8)	70.8±(2.2)	69.3±(5.7)
H. spontaneum	Hysun36	20.0±(7.0)	35.3±(4.1)	-5..6±(2.20)	28.7±(1.3)	37.4±(3.8)
H. spontaneum	Megasun	51.4±(3.9)	60.3±(3.5)	75.8±(6.9)	87.4±(6.3)	86.0±(5.4)
H. spontaneum	Urfloar	41.4±(1.4)	57.6±(9.6)	72.1±(6.0)	91.0±(3.5)	87.0±(4.3)
H. spontaneum	Allstar	42.8±(11.5)	61.5±(10.2)	68.2±(10.3)	79.5±(9.3)	82.4±(7.2)
H. spontaneum	Hysun33	48.6±(12.8)	65.1±(9.2)	57.6±(4.1)	76.4±(1.2)	77.9±(8.2)
T. aestivum	Alison	-9.6±(2.9)	25.4±(1.2)	38.2±(2.9)	66.4±(10.8)	42.9±(9.0)
T. aestivum	Blazar	-0.3±(0.4)	23.4±(1.5)	12.6±(1.6)	53.2±(3.0)	32.1±(1.4)
T. aestivum	Hysun25	-4.7±(0.6)	20.1±(2.1)	16.7±(0.8)	48.3±(1.8)	25.4±(1.5)
T. aestivum	Hysun36	-14.9±(2.6)	4.5±(0.8)	8.9±(1.3)	35.3±(1.4)	12.8±(7.8)
T. aestivum	Megasun	7.9±(0.8)	29.4±(9.7)	16.4±(6.0)	54.2±(2.2)	37.3±(10.1)
T. aestivum	Urfloar	9.6±(1.2)	26.1±(2.3)	20.0±(4.1)	42.4±(3.7)	27.6±(1.6)
T. aestivum	Allstar	8.2±(0.8)	25.0±(1.9)	11.7±(2.9)	51.4±(1.0)	31.6±(8.0)
T. aestivum	Hysun33	6.0±(0.9)	20.2±(2.3)	18.7±(2.9)	53.5±(1.6)	30.3±(8.3)
C. tinctorius	Alison	4.8±(0.6)	97.7±(0.3)	79.0±(2.3)	54.8±(3.3)	28.3±(3.2)
C. tinctorius	Blazar	2.3±0.7	97.7±(03)	76.8±(2.6)	52.3±(5.5)	35.4±(5.3)
C. tinctorius	Hysun25	5.5±(2.1)	97.7±(0.3)	69.6±(1.5)	42.8±(7.5)	29.6±(3.9)
C. tinctorius	Hysun36	6.0±(1.0)	97.7±(0.3)	60.5±(1.7)	17.8±(0.9)	9.3±(6.3)
C. tinctorius	Megasun	-10.3±(2.8)	97.4±(0.4)	-20.0±(1.0)	61.9±(4.1)	64.9±(3.0)
C. tinctorius	Urfloar	-12.3±(2.5)	97.4±(0.4)	-31.3±(9.9)	64.0±(4.3)	38.1±(5.1)
C. tinctorius	Allstar	-8.3±(3.0)	97.4±(0.4)	-64.8±(2.9)	58.8±(5.6)	30.9±(5.1)
C. tinctorius	Hysun33	-13.1±(2.8)	97.4±(0.4)	5.6±(1.5)	57.7±(3.2)	36.0±(3.7)
A. retroflexus	Alison	76.8±(8.7)	88.9±(4.3)	55.1±(4.5)	50.0±(6.9)	76.9±(1.5)
A. retroflexus	Blazar	95.7±(4.3)	95.0±(5.0)	86.7±(3.3)	87.6±(12.4)	78.5±(1.5)
A. retroflexus	Hysun25	88.1±(1.5)	94.6±(4.0)	78.8±(5.1)	80.0±(5.3)	68.8±(2.7)
A. retroflexus	Hysun36	66.9±(1.2)	75.8±(12.0)	47.7±(7.2)	62.2±(9.1)	63.3±(8.4)
A. retroflexus	Megasun	100.0±(3.0)	100.0±(0.0)	100.0±(2.0)	100.0±(0.0)	100.0±(0.0)
A. retroflexus	Urfloar	86.0±(9.0)	94.5±(3.5)	81.5±(9.5)	55.7±(2.3)	81.1±(3.6)
A. retroflexus	Allstar	96.7±(1.9)	99.0±(0.5)	94.3±(3.2)	100.0±(0.0)	96.5±(2.7)
A. retroflexus	Hysun33	98.5±(2.0)	99.8±(0.0)	96.8±(0.0)	100.0±(0.0)	99.6±(0.2)
P. oleracea	Alison	9.1±(0.1)	28.1±(2.1)	-39.2±(3.1)	84.1±(3.3)	8.9±(1.6)
P. oleracea	Blazar	16.5±(2.7)	40.4±(1.8)	-148.7±(9.1)	72.6±(6.7)	-42.8±(4.1)
P. oleracea	Hysun25	11.8±(2.1)	29.9±(3.1)	36.5±(2.1)	6.6±(0.9)	-52.5±(4.5)
P. oleracea	Hysun36	5.3±(1.0)	14.1±(3.0)	-10±(3.6)	-35.7±(8.3)	-35.3±(4.2)
P. oleracea	Megasun	27.5±(8.6)	49.1±(2.1)	79.8±(3.8)	24.0±(1.9)	1.4±(0.6)
P. oleracea	Urfloar	22.9±(7.0)	42.1±(2.6)	74.8±(3.7)	5.6±(1.2)	-48.4±(3.1)
P. oleracea	Allstar	22.4±(4.5)	40.2±(3.0)	77.4±(3.8)	22.5±(1.6)	-32.4±(3.7)
P. oleracea	Hysun33	14.4±(2.6)	30.5±(1.4)	76.3±(4.1)	22.2±(1.6)	17.4±(1.0)

Standard errors are given in parentheses

allelopathic extracts even stimulated some parameters: germination percentage of safflower seeds increased in the presence of sunflower extracts (Figure 1). However, it has previously been reported that three to seven tonnes of dry sunflower-residue matter per hectare have a negative allelopathic effect on the performance of wheat; in contrast, smaller amounts of allelopathic materials can improve wheat yield (Kaya et al., 2006). Boz (2003) has also found that allelopathic materials in wheat and rye (*Secale cereal*e) have no effect on later crops, but may inhibit some of their most important annual weeds. Cultivars showed differenence allelopathic potential (Table 1 and Figure 2). Extracts of Hysun 33 and Megasun most effectively inhibited germination indices (Figure 2). Allstar had the third-highest inhibitory effect. Hysun 36 had minimal impact, inhibiting all traits except germination rate by less than 20% (Figure 2). However, no cultivar inhibited germination rate less than 42%. Three new ionone-type bisnorsesquiterpenes and a new noribisabolene are potential allelopathic agents that have been isolated from sunflower var. SH.222 and VYP (Macias et al., 1998). Different concentrations of the extract gave significantly different results (Table 1 and Figure 3). The most effective deterrent was a concentration of 100%, and the least a concentration of 25% (Figure 3).

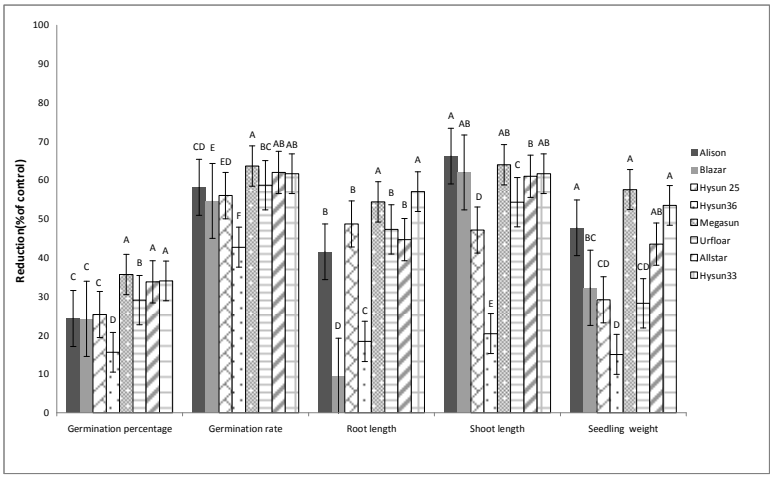

Fig 2. Allelopathic effect of eight sunflower cultivars on germination indices of target plants. Columns with the same letter at the top are not significantly different ($P < 0.05$); error bars represent standard error.

The interaction results showed that low concentrations actually stimulate some traits in wheat, safflower and *P. oleracea* (Table 3). Interactions between target plants and sunflower cultivars showed that *A. retroflexus* had the greatest sensitivity to cultivar extracts Megasun, Hysun 33, Allstar and Blazar (Table 2). The allelopathic materials extracted from Allstar and Hysun 36 had less impact on safflower. These results suggest that using sunflower extracts from Allstar can selectively control *A. retroflexus* in safflower crops with minimal effects on the safflower itself. The results also showed that Hysun 36, Blazer and Hysun 25 had the least negative impact on *L. rigidium*. Hysun 36 and Blazar also had less effect on *H. spontaneum*. The effects of the concentration of allelopathic material on target plants were significant (Table 1). Again, the highest reduction in the germination indices was in *A. retroflexus* at concentrations of 100 and 50% (Table 3). Twenty-five percent extract also significantly reduced all traits of *A. retroflexus* (Table 3). Seedling weight and shoot length in *H. spontaneum* at 100% concentration showed the highest reduction. The least reduction in root length and shoot height was in *P. oleracea* at 25 and 50% concentration. Twenty-five and 50% concentrations of extracts increased the seedling weight in *P. oleracea*, confirming the relative tolerance of this plant to sunflower allelopathy. Although the germination rate showed the highest reductions in response to extract concentrations, the other germination traits of safflower had little sensitivity to sunflower allelopathy (Table 3). Also, low concentrations of allelopathic materials (25%) most stimulated the traits of wheat. For example, 25% extract stimulated seed germination by 4.5 and 10% in safflower and wheat, respectively, compared with the control seed-germination percentage. This result agrees with other research into the stimulatory effect of sunflower allelopathy on plants (Anjum and Bajwa, 2007; Macias et al., 1998; Macias et al., 1999). Although some researchers have found that allelopathic sunflower material inhibits wheat growth, our results suggest that sunflower allelopathy can improve the growth of crops such as wheat and safflower, and its residues can reduce prolific weeds like *A. retroflexus*. The interaction of cultivars with concentration of extract showed that Megasun, Allstar and Hysun33 at 100% concentration caused the greatest reduction in target plants' germination percentage and rate, shoot height and seedling weight (Table 4). The most inhibition of root length at 100% concentration was observed with extracts from Hysun33, Megasun, Blazar and Alison. The effects of Alison, Blazar, Allstar and Hysun33 at 50% concentration in reducing germination in target plants were approximately equal to the effects of Allison and Hysun36 at 100% concentration. This suggests that extracts of cultivars that have severe allelopathic effects in low concentrations (such as Allstar and Hysun33) might be used as a biological herbicide if these cultivars do not have negative effect on crops (such as Alstar on safflower, see Table 2). The appropriate extracts could easily be applied in a rotation cycle for weed management, particularly in agricultural systems that can use little or no synthetic herbicide, such as organic farms.

Materials and methods

Sunflower (*Helianthus annuus* L.) Cultivars of Hysun 25, Hysun 33, Hysun36, Blazar, Urfloar, Megasun, Allstar and Alison were obtained from the experimental fields of Isfahan University of Technology in October 2009. These cultivars, recently introduced to Iran, are planted in most regions of the country. Leaves of sunflower cultivars were collected at mature stage from whole plants. The tissues were air-dried, then ground to a fine powder. Ten grams (dry weight) of leaf powder was soaked for 24 hours in 100 ml of distilled water at room temperature. The resultant solution was filtered through filter paper. (Hau et al., 2005). This solution was assumed as a stock solution (100% concentration); other concentrations were achieved from the stock solution. Weed seeds had been collected the previous year from wheat and sunflower fields in the Isfahan agricultural region and stored at room temperature for six to nine months to overcome dormancy. Crop seeds of wheat (*Triticum aestivum* L.)and safflower (*Carthamus tinctorius* L.) were also provided from farmers in this region. The seeds were sown on a Whatman No. 2 filter-paper seedbed in sterilized Petri dishes (9cm diam.). The filter papers were moistened with aqueous leaf extracts of the sunflower cultivars. Controls were similarly treated with distilled water. 30 seeds were germinated per Petri dish. The Petri dishes were put into sealed plastic bags to avoid moisture loss. Seeds were allowed to germinate at 25 ± 1°C and a 14-hour photoperiod for 14 days. Germination was considered to have occurred when the roots were 2 mm

Table 3. Interaction Effects of Target Plants and Concentration of Allelopathic Sunflower on the Inhibition Percentage of Target Plants' Germination Indices

Target plant	Extract concentration	Germination percentage inhibition (%)	Germination rate inhibition (%)	Root length inhibition (%)	Shoot height inhibition (%)	Seedling weight inhibition (%)
L. rigidum	100%	56.3±(5.0)	73.6±(3.1)	83.0±(3.6)	80.3±(4.1)	66.0±(3.8)
L. rigidum	50%	25.2±(5.2)	39.7±(4.7)	56.7±(8.5)	46.0±(4.7)	39.8+(4.7)
L. rigidum	25%	8.9±(0.4)	20.8±(3.9)	21.3±(1.2)	24.5±(4.2)	24.7±(3.4)
H. spontaneum	100%	71.4±(5.0)	84.2±(3.3)	88.8±(2.0)	99.6±(0.3)	96.0±(1.0)
H. spontaneum	50%	28.4±(4.4)	50.6±(3.6)	51.7±(7.0)	85.5±(3.6)	80.0±(3.5)
H. spontaneum	25%	0.5±(0.2)	17.5±(3.5)	1.5±(0.4)	25.0±(1.3)	34.6±(4.1)
T. aestivum	100%	10.8±(1.7)	55.8±(2.4)	59.5±(2.5)	89.4±(1.5)	60.5±(2.6)
T. aestivum	50%	0.0±(0.4)	17.3±(3.3)	16.1±(0.5)	50.8±(3.6)	28.7±(3.5)
T. aestivum	25%	-10.0±(1.8)	-7.9±(1.4)	-21.8±(3.4)	11.6±(2.6)	0.8±(2.1)
C. tinctorius	100%	1.0±(2.6)	97.6±(0.2)	43.1±(4.6)	63.3±(2.8)	46.5±(2.9)
C. tinctorius	50%	-6.1±(0.1)	97.6±(0.2)	13.4±(2.9)	51.7±(3.5)	32.7±(3.5)
C. tinctorius	25%	-4.4±(0.6)	97.6±(0.2)	9.2±(1.4)	38.8±(4.8)	22.9±(4.0)
A. retroflexus	100%	99.8±(0.2)	99.8±(0.2)	100.0±(0.0)	100.0±(0.0)	100.0±(0.0)
A. retroflexus	50%	97.5±(2.1)	99.0±(0.9)	94.1±(4.1)	94.8±(3.6)	100.0±(0.0)
A. retroflexus	25%	68.4±(7.2)	81.6±(5.1)	46.2±(11.9)	43.5±(2.3)	49.2±(2.7)
*P. olera*cea	100%	35.7±(3.9)	79.0±(2.8)	69.3±(4.7)	75.2±(7.4)	-16.9±(2.9)
*P. olera*cea	50%	6.4±(0.8)	18.9±(0.2)	11.9±(2.6)	4.7±(0.1)	-40.1±(4.7)
*P. olera*cea	25%	6.5±(0.4)	5.0±(0.6)	-22.7±(2.5)	-4.2±(0.7)	-37.9±(1.7)

Standard errors are given in parentheses

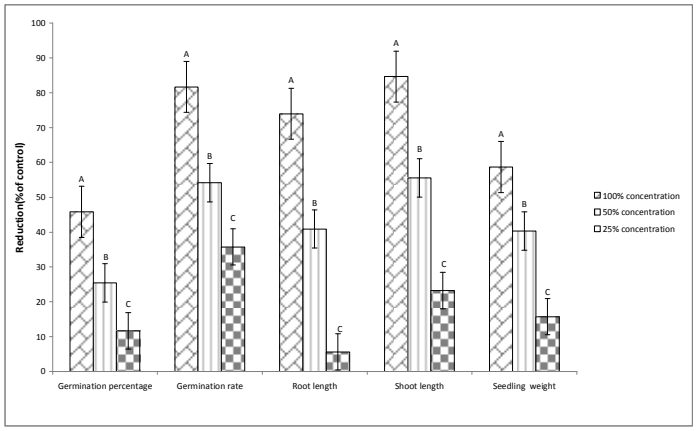

Fig 3. Allelopathic effects of three extract concentrations of sunflower on germination indices of target plants. Columns with the same letter at the top are not significantly different (P < 0.05); error bars represent standard error.

long. Germination percentage was recorded every 24 hours for 14 days. Root and shoot length and seedling dry biomass were recorded at the end of the experiment. Mean germination time (MGT) was calculated to assess the rate of germination (Ellis and Roberts, 1980). The experimental design was three factorial (8×4×6), arranged in a completely randomized block design with three replications. The first factor was leaf extracts of sunflower cultivars; the second was leaf-extract concentration (0, 25, 50 and 100%); and the third was target crop and weed species. The inhibition percentage (IP) for a given trait was calculated as follows (Mishra and Choudhuri, 1999):

$$IP = \left[1 - \frac{\text{sample extract}}{\text{control}}\right] \times 100$$

All data were analyzed using PROC GLM of SAS (9.1 versions) (SAS Institute 2001). Differences between the means were compared using LSD (P<0.05) and standard error values.

Conclusion

Results from this experiment showed that allelopathic chemicals of sunflower can potentially serve as an alternative herbicide against common broad- and narrow-leaf weeds in wheat and safflower.

However, this study did not find any cultivar extract that could control all weeds with no negative effect on wheat. For example, the extract of the Alison cultivar has less negative effect on whea t and more effectively inhibited *H. spontane-*

Table 4. Interaction Effects of Different Cultivars of Sunflower and Extract Concentration on the Inhibition Percentage of Target Plants' Germination Indices

Extract	Concentration	Germination percentage	Germination rate	Root length	Shoot height	Seedling weight
Alison	100%	31.5±(4.5)	75.7±(4.3)	72.2±(5.2)	86.0±(3.6)	66.7±(5.7)
Alison	50%	34.3±(4.4)	64.1±(7.9)	67.8±(5.1)	76.8±(4.6)	61.6±(7.5)
Alison	25%	7.2±(0.1)	34.7±(1.4)	-15.5±(2.8)	35.7±(2.2)	14.9±(0.5)
Blazar	100%	41.6±(2.6)	81.8±(3.9)	77.3±(3.9)	91.1±(2.9)	68.2±(6.6)
Blazar	50%	18.0±(1.1)	52.5±(4.3)	4.7±(0.6)	70.9±(2.5)	39.2±(1.8)
Blazar	25%	13.1±(1.7)	29.8±(1.1)	-53.4±(8.1)	24.1±(1.1)	-10.6±(1.7)
Hysun25	100%	41.3±(4.8)	80.0±(4.2)	71.7±(4.7)	84.0±(3.7)	46.3±(1.1)
Hysun25	50%	21.5±(2.9)	49.7±(6.2)	47.2±(4.6)	44.3±(1.8)	34.7±(1.7)
Hysun25	25%	9.1±(0.2)	36.0±(1.5)	24.2±(1.9)	10.3±(0.8)	2.6±(0.6)
Hysun36	100%	31.6±(8.3)	64.0±(6.4)	68.4±(4.7)	54.7±(2.9)	30.6±(1.6)
Hysun36	50%	15.4±(2.5)	39.9±(1.6)	8.9±(1.7)	22.8±(1.9)	16.5±(1.3)
Hysun36	25%	-0.2±(0.3)	24.3±(1.2)	-22.0±(1.9)	-16.2±(0.6)	-1.9±(0.2)
Megasun	100%	58.3±(0.6)	90.3±(2.9)	78.8±(7.9)	92.3±(2.7)	84.3±(3.3)
Megasun	50%	32.5±(2.0)	62.3±(7.5)	54.2±(1.3)	60.5±(8.5)	53.9±(5.0)
Megasun	25%	16.2±(0.5)	38.5±(1.5)	30.2±(3.1)	39.1±(1.2)	34.5±(1.4)
Urfloar	100%	51.4±(1.7)	85.6±(3.6)	67.8±(4.7)	88.5±(2.6)	65.4±(9.4)
Urfloar	50%	24.6±(1.0)	53.5±(4.4)	46.0±(2.4)	55.1±(1.4)	35.9±(4.4)
Urfloar	25%	11.2±(0.2)	37.0±(3.9)	28.2±(1.2)	19.4±(1.3)	18.2±(1.1)
Allstar	100%	57.2±(1.0)	89.5±(3.0)	71.8±(1.2)	93.2±(2.4)	71.8±(6.5)
Allstar	50%	28.4±(1.9)	54.8±(4.9)	40.7±(6.1)	55.3±(5.1)	31.0±(1.1)
Allstar	25%	15.7±(0.4)	41.7±(9.8)	21.5±(1.9)	34.6±(4.3)	27.7±(1.9)
Hysun33	100%	53.8±(1.8)	86.5±(3.6)	83.7±(4.9)	87.2±(3.5)	71.1±(6.8)
Hysun33	50%	27.4±(1.9)	54.2±(4.3)	55.6±(1.1)	59.2±(4.6)	48.9±(9.6)
Hysun33	25%	20.9±(1.8)	44.3±(1.0)	31.8±(2.0)	38.6±(8.1)	40.5±(7.2)

Standard errors are given in parentheses

eum, but has little impact on *L. rigidum*, *A. retroflexus* or *P. oleracea*. Even so, this result is an important finding in the control of *H. spontaneum* in wheat (many herbicides fail to control this weed selectively in wheat). Allelopathic materials from the Hysun36 and Allstar cultivars had minimal impact on safflowers as a crop. As the best and most practical extract is the one with the least phytotoxic effect on the target crop and the most effect on the weeds, it seems that Allstar extract may prove very important: it has little effect on safflower germination indices (except germination rate) and a negative affect on weeds including *A. retroflexus*, *P. oleracea*, *L. rigidum* and *H. spontaneum*. Our research also suggests that using sunflower allelopathy to control broad-leaf weeds, such as *Amaramthus reteroflexus*, may at the same time control narrow-leaf weeds such as *H. spontaneum* and *L. rigidum*. However, more experimentation in the allelopathic effects of sunflowers for weed control is needed in real greenhouse and field conditions.

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