

Research Article

Allelopathic effect of *Carthamus tinctorius* on weeds and crops

Marzieh Motamedi^a, Hassan Karimmojeni^{a*}, Fatemeh G. Sini^a

^a Department of Agronomy and Plant Breeding, College of Agriculture, Isfahan University of Technology, Isfahan, 84156-83111, Iran.

INFORMATION ARTICLE

Received: August 19, 2018

Accepted: December 17, 2018

Keywords:

allelopathy
sandwich method
safflower
weeds

***Corresponding author:**

<kmojeni@cc.iut.ac.ir>

Cite this article:

Motamedi M, Karimmojeni H, Sini FG.
Allelopathic effect of *Carthamus tinctorius*
on weeds and crops. *Planta Daninha*.
2020;38:e020212334
<https://doi.org/10.1590/S0100-83582020380100066>

Conflict of Interest:

The authors declare that there is no conflict of interest regarding the publication of this manuscript.

Copyright: This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided that the original author and source are credited.



HIGHLIGHTS

- Growth of weeds influenced by safflower residues depend on seed size and genotypes of safflower.
- Weed plants with smaller seed size were more sensitive to allelopathic residues.
- Radicle length was affected more by safflower residues in comparison to other growth traits.

ABSTRACT

Background: Allelopathic plants like safflower (*Carthamus tinctorius*) can be considered as natural herbicides for weeds management in field. But there is not enough research on safflower genotypes allelopathy potential.

Objective: So in this study, allelopathic effect of the four safflower genotypes on weeds (*Amaranthus* sp., *Hordeum spontaneum*), crops (*Sesamum indicum*, *Triticum aestivum*) and on autotoxicity of *Carthamus tinctorius* was evaluated in bioassay using sandwich method. The results can be used in the management of weeds in safflower fields and also in the rotation with other crops.

Methods: Two genotypes with high allelopathic potential and two genotypes with low allelopathic potential were selected from forty genotypes of safflower. Growth traits including radicle length, hypocotyl length, shoot length, fresh biomass weight and germination percentages were measured.

Results: Results showed that *Amaranthus* sp. and *C. tinctorius* displayed the most and least susceptibility to safflower residues, respectively. Khorasan (Khorasan330) and Egypt (PI657800) had the greatest with Kerman (CTNIR9) and Australia (PI 262424) had the least inhibitory effects on target plants. PI 262424 stimulated hypocotyl growth by 51%, 18% and 7% in *H. spontaneum*, *T. aestivum* and *C. tinctorius*, respectively. CTNIR9 enhanced this trait by 16% in *T. aestivum* and 10% in *C. tinctorius*. In large-seeded species (*H. spontaneum*, *T. aestivum* and *C. tinctorius*, Kerman (CTNIR9) and Australia (PI 262424) stimulated seedling growth.

Conclusion: It can be concluded that effectiveness of allelopathic residues of safflower on target plants depended on the seed size of target plant with smaller seed size (*Amaranthus* sp.) were more susceptible to allelopathic residues than those with larger ones. In addition radicle length was affected more than other growth traits by safflower residues.

1 INTRODUCTION

Weeds annually reduce the yield of commercial plants. Herbicides are the principal tool for weeds control. However, in recent years, many concerns have been raised about the use of herbicides and their negative impacts on the environment. Hence, many researchers have looked for appropriate ecological weed management via allelopathy (Khanh et al., 2007; Tsuzuki, 2003; Weston, 2005).

Allelopathy refers to both negative and positive effects of one plant species on the growth of another plant species via releasing chemical compounds named allelochemicals into the environment. The plant that releases allelochemicals is known as “donor plant” and the influenced plant by allelochemicals is called the “target” or “afflicted plant” (Inderjit and Duke, 2003).

Some crops and weeds can release chemicals such as phenol, alkaloids, fatty acids and flavonoids into their rhizosphere, which are able to enhance, reduce and even terminate germination and growth of nearby plants (Verma and Rao, 2006; Yamane et al., 1992; Inderjit and Duke, 2003; Yousefi Davood et al., 2013). Allelochemicals may disturb basic plant processes, such as hormonal balance, protein synthesis, respiration, photosynthesis, chlorophyll formation and plant water relations (Yamane et al., 1992). These biochemicals can act as natural herbicides for weeds control.

The presence of allelochemicals in various parts of plants, such as leaves, root, stem, flowers and pollen grains, is well-documented. Allelochemicals are released through foliar leaching, plant residue decomposition, root exudation and volatile emission. Due to direct exposure of root to the soil, it plays the most important role in releasing of allelochemicals into the environment (Yousefi Davood et al., 2013).

The use of allelopathy in weed management is of great significance and various methods, such as dish pack (Fujii et al., 2000), plant box (Yamaguchi and Fujii, 1994) and sandwich methods (Fujii et al., 2003) have been applied for assessment of the allelopathic effect of different plant species. The sandwich method is a less time-consuming bioassay method which can be applied to screen a large number of samples (Sekine et al., 2007).

Safflower (*Carthamus tinctorius* L.), which is grown throughout the world, has been regarded as a source of high-quality oil and red and orange pigments. Due to its well adaptation to various climates especially to

arid and semi-arid climates, safflower cultivation has been recently increased (Yousefi Davood et al., 2013).

Some research have been focused on the allelopathic potential of safflower. For example, significant reduction in the germination and root and shoot growth of wild barley (*Hordeum spontaneum* L.) as well as the great potential of safflower for management of this weed in wheat (*Triticum aestivum* L.) production have been reported by Miri (2011). It was also demonstrated that wild mustard seedling growth and seed germination were negatively affected by safflower allelopathic extract (Modhej et al., 2013). Furthermore, Bonamigo et al. (2013) reported that safflower aqueous extracts inhibited seedling emergence and early growth stages of canola (*Brassica napus* L.).

Allelopathic effects of Iranian safflower genotypes alongside non-Iranian genotypes has not been studied before. The aim of this study was to evaluate the allelopathic effect of four safflower genotypes, viz., Khorasan (Khorasan330), Egypt (PI 657800), Kerman (CTNIR9) and Australia (PI 262424) on two major weeds in safflower fields, i.e., *Amaranthus* sp., *H. spontaneum* and two crops, which have been used in crop rotation with safflower, i.e., *S. indicum*, and *T. aestivum*, and on autotoxicity of *Carthamus tinctorius*. To the best of our knowledge, this is the first report on the allelopathic effect of safflower plant on *Amaranthus* sp. and *S. indicum*.

2 MATERIALS AND METHODS

2.1 Plant material

Forty genotypes were randomly selected, cultivated and their potential was evaluated in a previous study (Motamedi et al., 2016). These genotypes were grown at the research farm of the Isfahan University of Technology located at Lavark, Najaf-Abad, Iran (40 km south-west of Isfahan, 32°32'N 51°23'E). Prior to crop planting 50 kg urea and 50 kg triple superphosphate were applied to the experimental area. Safflower seeds were sown by hand on 5th March 2012 at a density of fifty plants per m². Each trial plot was 2 m long and 1 m wide with 3 rows spaced 30 cm apart. No insecticide or fungicide was needed for the study based on standard agronomic practices. Irrigation was supplied when 45% of the total available water was depleted from the root zone to avoid water stress impact on plants. Safflower shoot residues, inflorescences, were collected from the field and stored separately in

paper bags in September 2012. These materials were air dried at room temperature and kept in plastic bags at room temperature until use.

The present study was carried out on four safflower genotypes [Khorasan (Khorasan330), Egypt (PI 657800), Kerman (CTNIR9) and Australia (PI 262424)] selected from 40 screened safflower genotypes. Khorasan (Khorasan330) and Egypt (PI 657800) genotypes had the most inhibitory effects and Kerman (CTNIR9) and Australia (PI 262424) genotypes had the least inhibitory effects.

To break seed dormancy in wild barley (*H. spontaneum*), 24 Petri dishes and Erlenmeyers were sterilised in an autoclave at 121 °C and transferred to the tissue culture room. The seeds were surface sterilised for 2.5 min with 70% ethanol and rinsed thoroughly with sterilised distilled water for five times. Then, seeds were sterilised with 5% sodium hypochlorite for 15 min and six times rinsed with sterilised distilled water. Twenty-five seeds were placed in each Petri dish and transferred to the refrigerator (2 °C). Different treatment times i.e., 3, 4, 5, 6, 7, 8, 9, and 10 days, with three replicates were used to evaluate the needed time for breaking seed dormancy. Then, Petri dishes in each treatment were transferred to the incubator (25 °C). The number of germinated seeds was counted after 24, 48, and 72 hours. The 8th day of treatment was the most effective time for breaking seed dormancy in wild barley.

2.2 Preparation and method of growth

The Sandwich method (Fujii et al., 2003) was used to evaluate the allelopathic effect of shoot residues of safflower genotypes. For this purpose, 0.4 g shoot residue of each genotype was placed in a sterile Petri dish and with two layers of agar (each 5 mL) poured on the dried residue. Thirty seeds from each target plant were placed on agar medium. Petri dishes were sealed with parafilm and wrapped in aluminium foil to create dark conditions. Petri dishes were then incubated in a germinator (Arvin 700L) (11:13 h light:dark; 13-25 °C) for a week. The control

was constituted by growing plant seeds without safflower shoot residues. Following incubation, radicle length, hypocotyl length, shoot length and fresh biomass were measured and germination percentage was recorded. In order to measure the length of hypocotyl and radicle, these sections were initially cut from border node and then the length of each section was measured.

The inhibition/stimulation ratio was calculated using the following equation (Ahn et al., 2005):

$$\text{Inhibition/stimulation ratio} = [\text{control} - \text{treated}] \times 100$$

2.3 Statistical analysis

The study was conducted as a factorial experiment, using a completely randomised design with 3 replicates. The safflower genotypes (four genotypes) were considered the first factor and the target plants (five levels: *Amaranthus* sp., *H. spontaneum*, *S. indicum*, *T. aestivum* and *C. tinctorius*) were the second factor. All collected data were analysed via SAS software system and mean comparisons were performed using LSD test at $\alpha = 0.05$.

3 RESULTS AND DISCUSSION

Safflower genotypes and target plants showed significant differences for all measured traits at the 1% probability level. The genotypes \times target species interaction was also significant ($\alpha = 0.01$) for all traits, except for shoot length (Table 1). Khorasan (Khorasan330) and Egypt (PI657800) had the most inhibitory effects on the growth traits, with their effectiveness dependent on the target plant type. Kerman (CTNIR9) and Australia (PI 262424) had the least inhibitory effects on target plants and in some species, these genotypes stimulated seedling growth. The result of the present study shows that genetic variation is involved in allelopathic effects. Therefore, the type of allelopathic properties of genotypes needs to be considered in weed management. In almost all treated species, four safflower genotypes were able to inhibit the radicle length, hypocotyl length, shoot length, fresh biomass weight and germination percentage.

Table 1 - Analysis of variance of growth traits of target species allelopathically affected by four studied safflower genotypes.

Source of variation	Degrees of freedom	Radicle length (cm)	Hypocotyl length (cm)	Shoot length (cm)	Fresh biomass weight (g)
Safflower genotypes	3	0.12805**	1.92940**	2.12421**	2.23274**
Target species	4	1.37976**	10.29892**	11.35165**	21.23251**
Safflower genotypes \times target species	12	0.01364**	0.31415**	0.15130 ^{n.s}	0.34845**
Experimental error	40	0.00460	0.04845	0.14516	0.03879
CV%		9.01209	15.48312	21.88256	10.37162

The values under each trait are mean square. *, ** Significant at 5% and 1% probability level, respectively.

3.1 Allelopathic effect of safflower on *Hordeum spontaneum*

Radicle length, hypocotyl length, shoot length, and fresh biomass weight of wild barley seedlings were significantly ($\alpha = 0.01$) affected by safflower shoot residues (Table 2). The results showed that Kerman (CTNIR9) had the least inhibitory effect (19.82%) and Egypt (PI 657800) had the highest inhibitory effect (46.37%) on the root length seedlings (Table 3). Allelopathic effects of Australia (PI 262424) and Khorasan (Khorasan330) inhibited the root length by 21.23% and 40.66%, respectively.

Kerman (CTNIR9) had the least (1.01%) and Khorasan (Khorasan330) had the most (35.89%) inhibitory effects on the hypocotyl length (Table 3). Egypt (PI 657800) inhibited the hypocotyl length of seedlings by 30.73%. Australia (PI 262424) with 50.68% stimulatory effect increased hypocotyl length. Australia (PI 262424) had the least (16.17%) and Khorasan (Khorasan330) had the most (35.37%) inhibitory effects on the shoot length (Table 3). Kerman (CTNIR9) and Egypt (PI 657800) decreased the shoot length by 17.74% and 35.33%, respectively.

The results showed that Kerman (CTNIR9) with 6.11% had the lowest and Egypt (PI657800) genotype with 40.92% had the highest inhibitory effects on the fresh biomass weight. There were no significant differences between Australia (PI 262424) (7.73% inhibitory effect on fresh biomass weight) and Kerman

(CTNIR9); and Khorasan (Khorasan330) (38.86% inhibitory effect on fresh biomass weight) and Egypt (PI657800) (Table 3).

Our result is in agreement with that of Miri (2011), who reported the allelopathic effect of safflower plant on wild barley growth. He studied the allelopathic potential of some important crop species on wild barley, a major weed of wheat in Iran. Most crop species inhibited wild barley germination and radicle growth. The highest inhibitory effects were caused by safflower. Leaf extract of safflower reduced wild barley germination, root and shoot growth by 68.3%, 54.8%, and 52.6%, respectively. Phytotoxic effect of safflower stem extracts inhibited germination, root and shoot growth by 84.2%, 4.6%, and 4.3%. Safflower root extract also led to the reduction in radicle and shoot length, and germination percentage by 38.2%, 41.7% and 72.9 (Miri, 2011).

3.2 Allelopathic effect of safflower on *Amaranthus sp.*

The allelopathic effect of safflower on *Amaranthus sp.* has been surveyed for the first time in the present study. The analysis of variance (Table 2) showed that there were significant differences between four selected safflower genotypes in terms of the effect on the radicle length, hypocotyl length and shoot length of *Amaranthus sp.* seedlings at the 5% probability level. The fresh biomass of *Amaranthus sp.* Seedlings was not affected significantly by the residues of four safflower genotypes.

Table 2 - Variance analysis of growth traits of each target plant affected by four studied safflower genotypes

Source of variation	Degree of freedom	Radicle length (cm)	Hypocotyl length (cm)	Shoot length (cm)	Fresh biomass weight (g)
<i>Hordeum spontaneum</i> Linn.					
Safflower genotypes	3	0.09331**	0.93212**	0.51602**	1.11764**
Experimental error	8	0.00617	0.18390	0.03895	0.01885
CV%		8.27703	19.81690	10.39970	5.32076
<i>Amaranthus sp.</i>					
Safflower genotypes	3	0.00157*	0.00053*	0.00146*	2.27977 ^{ns}
Experimental error	8	0.00028	0.00010	0.00022	1.84741
CV%		8.75046	5.72399	11.01770	13.54460
<i>Sesamum indicum</i> Linn.					
Safflower genotypes	3	0.00801*	0.01159 ^{ns}	0.41510*	0.00087 ^{ns}
Experimental error	8	0.00434	0.01891	0.03567	0.01661
CV%		9.02152	12.59370	12.53310	13.61570
<i>Triticum aestivum</i> Linn.					
Safflower genotypes	3	0.04532**	1.46740**	0.72141 ^{ns}	1.01955**
Experimental error	8	0.00577	0.11390	0.36111	0.10840
CV%		7.98171	13.64720	19.58920	10.84431
<i>Carthamus tinctorius</i> Linn.					
Safflower genotypes	3	0.03451*	1.19043**	0.65877*	1.48076**
Experimental error	8	0.00649	0.12032	0.14583	0.04504
CV%		8.39021	16.03852	16.16830	7.56860

The values under each trait are mean square. *, ** Significant at 5% and 1% probability level, respectively.

The results displayed that Kerman (CTNIR9) with 35.03% had the least and Khorasan (Khorasan330) with 56.85% had the highest inhibitory effect on the radicle length in *Amaranthus* sp. seedlings. The inhibitory effects on the *Amaranthus* sp. radicle length for Egypt (PI657800) and Australia (PI 262424) were 53.42% and 40.23%, respectively. Australia (PI 262424) with 40.6% had the least inhibitory effect and Khorasan (Khorasan330) with 47.57% had the most inhibitory effect on the hypocotyl length in *Amaranthus* sp. There was no significant difference between Kerman (CTNIR9) (41.87% inhibitory effect on hypocotyl growth) and Australia (PI 262424). No significant difference was also found between Egypt (PI657800) (45.33% inhibitory effect on hypocotyl growth) and Khorasan (Khorasan330) (Table 3).

Kerman (CTNIR9) with 27.01% and Khorasan (Khorasan330) with 45.26% showed respectively the least and the most inhibitory effects on the shoot growth of *Amaranthus* sp. seedlings. There were no significant difference between Kerman (CTNIR9) and Australia (PI 262424) with 38.19%, Egypt (PI657800) genotype with 42.29% inhibitory effect and Khorasan (Khorasan330) (Table 3).

The lowest inhibitory effects on the fresh biomass weight of *Amaranthus* sp. was found for Kerman (CTNIR9) with 33.14% while the highest inhibition

was in case of Egypt (PI657800) with 48.04%. The inhibitory effects for Khorasan (Khorasan330) and Australia (PI 262424) were as 45.62% and 37.05%, respectively.

3.3 Allelopathic effect of safflower on *Sesamum indicum*

The allelopathic effect of safflower on *S. indicum* has not been evaluated previously. The analysis of variance (Table 2) showed that there were statistically significant differences between four selected safflower genotypes in terms of the effect on the radicle length and shoot length in *S. indicum* seedlings, but the hypocotyl length and fresh biomass weight were not affected by different safflower residues.

Comparison of inhibitory effects of safflower genotypes on the radicle length in *S. indicum* seedlings showed that the lowest inhibitory effects were due to Australia (PI 262424) with 24.55% while the highest inhibitory effects found for Egypt (PI657800) with 30.84%. The inhibitory effects of Kerman (CTNIR9) and Khorasan (Khorasan330) were 25.34% and 26.28%, respectively. With regard to the hypocotyl length, Australia (PI 262424) with 31.53% and Egypt (PI657800) with 40.88% had the least and the most inhibitory effects, respectively. The inhibitory effects on the hypocotyl growth for Kerman

Table 3 - Effect of four safflower genotypes on growth traits of seedlings of *Amaranthus* sp., *Hordeum spontaneum*, *Sesamum indicum*, *Triticum aestivum* and *Carthamus tinctorius*

Safflower genotype	Radicle length (cm)	Hypocotyl length (cm)	Shoot length (cm)	Fresh biomass weight (g)
<i>Hordeum spontaneum</i>				
Khorasan (Khorasan330)	0.791 b	1.390 b	1.590 b	2.102 b
Egypt (PI 657800)	0.792 b	1.720 b	1.761 b	2.011 b
Kerman (CTNIR9)	1.110 a	2.310 a	2.621 a	3.191 a
Australia (PI 262424)	1.080 a	2.150 a	2.640 a	3.012 a
<i>Amaranthus</i> sp.				
Khorasan (Khorasan330)	0.140 b	0.161 c	0.120 b	0.003 a
Egypt (PI 657800)	0.161 ab	0.170 bc	0.151 b	0.003 a
Kerman (CTNIR9)	0.191 a	0.190 ab	0.172 a	0.004 a
Australia (PI 262424)	0.180 a	0.191 a	0.160 a	0.003 a
<i>Sesamum indicum</i>				
Khorasan (Khorasan330)	0.721 ab	1.060 a	1.151 b	0.931 a
Egypt (PI 657800)	0.672 b	1.011 a	1.252 b	0.870 a
Kerman (CTNIR9)	0.731 ab	1.131 a	1.950 a	0.980 a
Australia (PI 262424)	0.790 a	1.150 a	1.6510 a	0.991 a
<i>Triticum aestivum</i>				
Khorasan (Khorasan330)	0.812 b	1.891 c	2.012 a	2.550 b
Egypt (PI 657800)	0.881 b	1.971 c	2.240 a	2.521 b
Kerman (CTNIR9)	1.041 a	2.620 b	2.901 a	3.641 a
Australia (PI 262424)	1.060 a	3.401 a	3.011 a	3.422 a
<i>Carthamus tinctorius</i>				
Khorasan (Khorasan330)	0.870 b	1.570 b	2.110 ab	2.152 b
Egypt (PI 657800)	0.852 b	1.701 b	1.821 b	2.231 b
Kerman (CTNIR9)	1.042 a	2.891 a	2.71 a	3.450 a
Australia (PI 262424)	1.061 a	2.470 a	2.790 a	3.370 a

For each target species, means followed by the same letter do not differ significantly at the 5% probability level according to the LSD test.

(CTNIR9) and Khorasan (Khorasan330) were 32.55% and 39.23%, respectively.

Kerman (CTNIR9) with 19.7% had the least and Khorasan (Khorasan330) with 41.27% had the most inhibitory effects on the shoot length. No significant differences were observed between Australia (PI 262424) with 22.73% and Kerman (CTNIR9) and Egypt (PI657800) with 37.03% inhibitory effect on the shoot length and Khorasan (Khorasan330) (Table 3).

The least and the most inhibitory effects on the fresh biomass were found in case of Australia (PI 262424) (21.37%) and Egypt (PI657800) (45.87%), respectively. The inhibitory effects on the fresh biomass weight for Khorasan (Khorasan330) and Kerman (CTNIR9) were 44.87% and 26.16%, respectively.

3.4 Allelopathic effect of safflower on *Triticum aestivum*

The data indicated that shoot residues of different safflower genotypes had significant effects on the radicle length, hypocotyl length, and fresh biomass weight of wheat seedlings at 1% probability level and non-significant effects on the shoot length (Table 2). Australia (PI 262424) with 14.47% had the least and Khorasan (Khorasan330) with 43.12% had the most inhibitory effects on the radicle length. No significant difference was found between Australia (PI 262424) and Kerman (CTNIR9) with 16.74% inhibitory effect on the radicle length. There was also no significant difference among Khorasan (Khorasan330) and Egypt (PI657800) with 40.18% inhibitory effect on radicle growth (Table 3).

These findings indicated that Khorasan (Khorasan330) with 35.64% had the highest inhibitory effect on the hypocotyl length seedlings. No significant difference was found between Khorasan (Khorasan330) and Egypt (PI657800) with 20.4% inhibitory effect on hypocotyl growth. Australia (PI 262424) with 17.86% had the highest stimulatory effect on hypocotyl length and lead to increase in hypocotyl length. Also, Kerman (CTNIR9) with 16.31% stimulatory effect stimulated the hypocotyl growth.

Australia (PI 262424) with 14.89% had the least and Khorasan (Khorasan330) with 34.87% had the most inhibitory effect on the shoot length. The inhibitory effect of Kerman (CTNIR9) was 15.71% and for Egypt (PI657800) was 34.8%. Kerman (CTNIR9) with 5.64% had the least and Egypt (PI657800) with 38.17% had the most inhibitory effects on the fresh biomass.

There was no significant difference between Egypt (PI657800) and Khorasan (Khorasan330) with 35.33% inhibitory effect on the fresh biomass weight. There was also no significant difference between Kerman (CTNIR9) and Australia (PI 262424) with 7.46% inhibitory effect on the fresh biomass weight (Table 3).

3.5 Autotoxicity of safflower on *Carthamus tinctorius*

Autotoxicity of different safflower genotypes affected the radicle length and shoot length ($P < 0.05$) and the hypocotyl length and fresh biomass weight at 1% probability level (Table 2). Australia (PI 262424) with 8.62% had the least and Egypt (PI657800) with 33.61% had the most inhibitory effect on the radicle growth. No significant difference was observed between Australia (PI 262424) and Kerman (CTNIR9) with 11.26% inhibitory effect. There was also no significant difference between Egypt (PI657800) and Khorasan (Khorasan330) with 26.57% inhibitory effect on the radicle length.

Khorasan (Khorasan330) with 16.2% had the most inhibitory effect on the hypocotyl length. No significant difference was found between Khorasan (Khorasan330) and Egypt (PI657800) with 12.66% inhibitory effect on the hypocotyl length. Kerman (CTNIR9) with 9.6% stimulatory effect, caused to increase in the hypocotyl length. There was also no significant difference between Kerman (CTNIR9) and Australia (PI 262424) with 6.56% stimulatory effect on the hypocotyl length (Table 3).

Australia (PI 262424) with 12.98% had the least and Egypt (PI657800) with 34% had the most inhibitory effect on the shoot length no significant difference was found between Egypt (PI657800) and Khorasan (Khorasan330) with 24.68% inhibitory effect on the shoot length. There was also no significant difference between Australia (PI 262424) and Kerman (CTNIR9) with 15.32% inhibitory effect on the shoot growth (Table 3, $p < 0.05$).

In case of the fresh biomass, the least inhibitory effect (1.7%) was found for Kerman (CTNIR9) while Khorasan (Khorasan330) with 16.77% had the most inhibitory effect. There was no significant difference between Khorasan (Khorasan330) and Egypt (PI657800) with 10.49% inhibitory effect on the fresh biomass weight. There was also no significant difference between Kerman (CTNIR9) and Australia (PI 262424) with 5.62% inhibitory effect on the fresh biomass (Table 3). Yousefi Davood et al. (2013) showed that the growth parameters of cultivated

safflower were stimulated by the wild safflower (*C. oxycantha* M. Bieb) allelopathy. They also found that the cultivated safflower seedlings inhibited the germination parameters of the wild safflower.

All four safflower genotypes inhibited germination and growth traits in almost all studied species. In large-seeded species (*Hordeum spontaneum* L., *Triticum aestivum* L. and *Carthamus tinctorius* L.), Kerman (CTNIR9) and/or Australia (PI 262424) stimulated seedling growth. PI 262424 stimulated hypocotyl growth by 50.68%, 17.87% and 6.56% in wild barley, wheat and *C. tinctorius*, respectively. CTNIR9 stimulated this trait by 16.31% in wheat and 9.6% in *C. tinctorius*. The effectiveness of allelopathic residues on target plants depended on the seed size of target plants. The results showed that target plants with smaller seed size were more sensitive to allelopathic residues. In this study, *Amaranthus* sp. displayed the most and *C. tinctorius* showed the least susceptibility to shoot residues of safflower. As reported by Mohler (1996), released phytotoxins from green manure residues had greater effects on small-seeded species than on large-seeded species. Small-seeded species have fewer reserves to support seedling respiration during stress-induced carbon deficit periods and have less ability to detoxify allelochemicals. Similarly, Liebman and Liebman (2006) reported that larger seeds could tolerate allelochemicals and extracted phytotoxins from red clover shoots due to their greater amounts of seed reserves. Seibert and Pearce (1993) found that larger-seeded species have more tolerance to stresses. Small-seeded species tend to have greater amounts of root length per unit of root mass and greater amounts of the absorptive surface area through which allelochemicals might enter. Our results are consistent with the results of the previous studies indicating the sensitivity of small-seeded species to the allelopathic effect of residues due to having fewer seed reserves.

Our findings revealed that radicle length was affected more by safflower residues compared to other growth traits. Similarly, Jafarieh Yazdi and Javidfar (2011) compared the allelopathic effects of some Brassica species in two growth stages on germination and growth of sunflower. They indicated that root elongation was affected more than hypocotyl elongation and it might be due to the direct contact of root with inhibitory chemicals. Previous studies also indicated that root was the most susceptible part of the plant to phytotoxic compounds (Alam, 1990; Burgos and Talbert, 2000;

Chung and Miller, 1994; Leather and Einhellig; 1986; Liebman and Sundberg, 2006; Martin et al., 1990; Pederson, 1986; Wu, 2000). In our study, the root of *Amaranthus* sp. showed the most sensitivity and the root of *C. tinctorius* had the least sensitivity to allelopathic effects of safflower residues. These results might lead researchers to have a better understanding of allelopathy and to find a new weed management approach. Further research is indicated to elucidate the components of allelochemicals present in plants.

4 CONCLUSIONS

Radicle length was affected more than other growth traits by safflower residues. Our findings also demonstrated that effectiveness of allelopathic residues on target plants depended on the seed size of target. As, it was observed that *Amaranthus* sp., wild barley, *S. indicum*, wheat and *C. tinctorius*. Seedlings are sensitive to the allelopathic effect of safflower residues and plants with smaller seed size (*Amaranthus* sp.) were more susceptible to allelopathic residues than those with larger ones.

5 CONTRIBUTIONS

HK: Concept and experimental protocol for the study; MM: experiments and data analysis; HK, MM, FG: manuscript preparation.

6 ACKNOWLEDGEMENTS

This study was supported by Isfahan University of Technology.

7 REFERENCES

- Ahn JK, Hahn SJ, Jung-Tae K, Khanh TD, Chung IM. Evaluation of allelopathic potential among rice (*Oryza Sativa* L.) germplasm for control of *Echinochloa crus-galli* P. Beauv in the field. *Crop Prot.* 2005;24(5):413-19. <https://doi.org/10.1016/j.cropro.2004.09.009>.
- Alam SM. Effect of wheat straw extract on the germination and seedlings growth of wheat (cv. Pavon). *Wheat Information Service.* 1990;71:16-18.
- Bonamigo T, Fortes AMT, Pinto TT, Gomes FM, Silva J, Bu-turi CV. Allelopathic interference of safflower leaves with oilseed species. *Biotemas.* 2013; 26(2): 1-8. <http://dx.doi.org/10.5007/2175-7925.2013v26n2p1>
- Burgos NR, Talbert RE. Differential activity of allelochemical from secale *Secale cereale* in seedling bioassay. *Weed Sci.* 2000;48(3):302-10. <https://doi.org/10.1614/0043-1745>.
- Chung IM, Miller DA. Natural herbicide potential of alfalfa residues on selected weed species. *Agron J.* 1994;87(5):920-5. <https://doi:10.2134/agronj1995.00021962008700050024x>.

- Fujii Y, Matsuyama M, Hiradate S, Nakatani K. Development of new bioassay for volatile allelochemicals: Dish-pack method. *J Weed Sci Tech*. 2000;45:80-1. <https://doi.org/10.3389/fpls.2013.00375>.
- Fujii Y, Parvez SS, Parvez MM, Ohmae Y, Iida O. Screening of 239 medicinal plant species for allelopathic activity using the sandwich method. *Weed Biol. Manag*. 2003;3(4):233-41. <https://doi.org/10.1046/j.1444-6162.2003.00111.x>
- Inderjit, Duke SO. Ecophysiological aspects of allelopathy. *Planta*. 2003;217(4):529-39. <https://doi.org/10.1007/s00425-003-1054-z>.
- Jafariehyazdi E, Javidfar F. Comparison of allelopathic effects of some brassica species in two growth stages on germination and growth of sunflower. *Plant Soil and Environ*. 2011;57(2):52-6.
- Khanh TD, Xuan TD, Chung IM. Rice allelopathy and the possibility for weed management. *Ann Appl Biol*. 2007;151(3):325-39. <https://doi.org/10.1111/j.1744-7348.2007.00183.x>.
- Leather GR, Einhellig FA. Bioassays in the study of allelopathy. In Putnam AR, and Tang CS, eds. *The Science of Allelopathy*. New York: John Wiley. 1986;p:133-5.
- Liebman M, Sundberg DN. Seed mass affects the susceptibility of weed and crop species to phytotoxins extracted from red clover shoots. *Weed Sci*. 2006;54(2):340-5.
- Martin VL, McCoy LE, Dick WA. Allelopathy of crop residues influences corn seed germination and early growth. *Agron J*. 1990;82:555-60. <https://doi.org/10.2134/agronj1990.00021962008200030024x>.
- Miri HR. Allelopathic potential of various plant species on *Hordeum spontaneum*. *Adv Environ Biol*. 2011;5(11):3543-49.
- Modhej A, Rafatjoo A, Behdarvandi B. Allelopathic inhibitory potential of some crop species (wheat, barley, canola, and safflower) and wild mustard (*Sinapis arvensis*). *Int J Biosci*. 2013;3:212-20.
- Mohler CL. Ecological bases for the cultural control of annual weeds. *J Prod Agri*. 1996;9(4):468-74. <https://doi.org/10.2134/jpa1996.0468>.
- Motamedi M, Karimmojeni H, Ghorbani Sini F. Evaluation of allelopathic potential of safflower genotypes (*Carthamus tinctorius* Linn.). *J Plant Prot Res*. 2016;56(4):352-9.
- Pederson GA. White clover seed germination in agar containing tall fescue leaf extracts. *Crop Sci*. 1986;26(6):1248-9. <https://doi.org/10.2135/cropsci1986.0011183X002600060036x>.
- Seibert AC, Pearce RB. Growth analysis of weed and crop species with reference to seed weight. *Weed Sci*. 1993;41(1):52-6.
- Sekine T, Mami S, Azizi M, Yoshiharu F. Antifungal effects of volatile compounds from black zira (*Bunium persicum*) and other spices and herbs. *J Chem Ecol*. 2007;33(11):2123-32. <https://doi.org/10.1007/s10886-007-9374-2>.
- Tsuzuki E. Buckwheat allelopathy: Use in weed management. *Allelopathy J*. 2003;12(1):1-11.
- Verma M, Rao P. Allelopathic effect of four weed species extracts on germination, growth and protein in different varieties of *Glycine max* (L.) Merrill. *J Environ Biol*. 2006;27(3):571-7.
- Weston LA. History and current trends in the use of allelopathy for weed management. *HortTechnology*. 2005;15(3):529-34.
- Wu H, Pratley J, Lemerle D, Haig T. Evaluation of seedling allelopathy in 453 wheat (*Triticum aestivum*) accessions against annual ryegrass (*Lolium rigidum*) by equal-compartment-agar method. *Aust J Agric Res*. 2000;51:937-44.
- Yamaguchi H, Fujii Y. Allelopathic of cultivated and weed azuki Beans – assessment of allelopathic activity by plant box method. *J Weed SciTech*. 1994;33:138-9.
- Yamane A, Nishimura H, Mizutani J. Allelopathy of yellow field cress (*Rorippa sylvestris*). *J Chem Ecol*. 1992;18:683-91.
- Yousefi Davood M, Karimmojeni H, Khodae MM, Sabzalian MR. A bioassay assessment of safflower allelopathy using equal compartment agar methods. *J Agrobiol*. 2013;30(2):97-106. <https://doi.org/10.2478/agro-2013-0010>.