Agrotechniques in Industrial Crops

Journal Homepage: https://atic.razi.ac.ir

Effects of Various Plant Extracts on the Seedling Development of *Cichorium intybus* and *Alopecurus myosuroides*

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ARTICLE INFO

Original paper

Article history:
Received: 28 Dec 2024
Revised: 01 Apr 2025
Accepted: 07 Jun 2025

Keywords:
Allelochemical
Germinated seeds
Hydroethanolic extract
Natural herbicide
Weed

ABSTRACT

The study aimed to assess the impact of extracts from plant species on the early growth of *Cichorium intybus* and *Alopecurus myosuroides* weeds in laboratory and greenhouse. In the laboratory, the tested extracts included Papaver fruits, Harmel seeds, Fenugreek seeds, Artichoke leaves, Peanut shoots, Camelina shoots, Juglans fruit skins, and Pomegranate fruit skins at concentrations of 6.25, 12.5, 25, 50, 75, and 100 $g.l^{-1}$. Distilled water and trifluralin were assigned as the controls, respectively. The most potent inhibitory extracts, Artichoke, Peanut, Pomegranate, and Papaver, at concentrations of 25, 50, 75, and 100 $g.l^{-1}$ in addition to distilled water and glyphosate were applied to *C. intybus* and *A. myosuroides* under greenhouse conditions. All the extracts resulted in reduced seed early growth and photosynthetic parameters for both weed species. The phytotoxicity effect of the extracts intensified with 100 and 75 $g.l^{-1}$, showing the most significant inhibitory effects. The hydroalcoholic extracts of Papaver fruit and Artichoke leaf, which had the highest total phenolic and alkaloid content, demonstrated the most significant herbicidal activity. Plant extracts containing allelochemical properties hold promise for the development of eco-friendly herbicides as substitutes for conventional chemical herbicides.

DOI: 10.22126/ATIC.2026.11555.1184

1. Introduction

Weeds are indeed a significant factor that limits food production in agricultural systems globally. They exert negative effects on both the quality and quantity of agricultural products by competing with crops for essential resources such as water, light, nutrients, and space (Lopes *et al*., 2022). The impact of weeds on yield could potentially lead to a complete loss of production, reaching up to 100%, varying based on the specific crop and season, if not controlled (Khatun *et al*., 2022).

Cichorium intybus L. is a diploid, perennial plant belonging to the *Asteraceae* family. It is self-incompatible and exhibits wide phenotypic diversity, often bearing light blue flowers. Native to the Mediterranean region, this species has spread to temperate and semi-arid regions worldwide. In North America and Australia, *C. intybus* has become an invasive weed, classified as a noxious weed in Colorado (Birsa and Sarbu, 2023; Závada *et al*., 2017). *C. intybus* in Iran is also one of the most problematic broadleaf weeds in chickpea fields in Kermanshah, Kurdistan, and Hamadan provinces (Veisi *et al*., 2022).

Alopecurus myosuroides Huds. is a narrow-leaved annual weed commonly found in cultivated and uncultivated areas. This weed exhibits a wide distribution spanning more than 60 countries in the temperate regions of Europe and Asia. (Li *et al*., 2022). *A. myosuroides* is commonly found in winter crops. Peak germination and emergence occur in early fall, coinciding with the planting and early growth stages of winter cereals (Alwarnaidu Vijayarajan *et al*., 2021). The presence of *A. myosuroides* weed is predominantly noted between October and December, with around 80% of the population emerging in the northwestern region of Europe. This species typically hibernates in

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two developed leaves or the tillering stage during the winter months. Upon the arrival of spring, it resumes growth and completes its life cycle before the harvest season, producing a significant number of seeds (Pintar *et al*., 2021).

Various methods have been developed to manage weeds in agricultural systems over time. These methods include the use of herbicides, as well as manual and mechanical removal (Alsharekh *et al*., 2022). While chemical herbicides have traditionally been favored for their high efficiency in weed control, their indiscriminate use has led to the development of herbicide-resistant weeds and increased negative impacts on crops, human health, and the environment (Maestre Rodríguez *et al*., 2023). Currently, herbal herbicides derived from plant extracts containing allelopathic properties have demonstrated significant potential in combating weeds. This eco-friendly approach to weed control is increasingly garnering attention and recognition for its effectiveness (Abdel-Farid *et al*., 2021; Hasan *et al*., 2021). The impact of allelochemicals on other plants is contingent upon both the concentration absorbed and the sensitivity of the recipient plants (Popoola *et al*., 2020). These chemical compounds naturally occur in various plant parts such as roots, seeds, leaves, and stems (Alsharekh *et al*., 2022). Phenolic compounds represent a significant category of allelochemicals produced by diverse plant species. Within this group, various compounds, including phenolics and their degradation products, exhibit potent phytotoxic properties (Mousavi *et al*., 2021).

Numerous studies have indicated that plant extracts containing allelochemicals can function as potent natural herbicides. The application of secondary plant compounds has proven to be successful in weed management within agricultural settings (El-Mergawi and Al-Humaid, 2019; Khatun *et al*., 2022; Poonpaiboonpipat *et al*., 2021). In a study by Kaab et al. (2020), it was found that the methanolic extract of Artichoke (*Cynara cardunculus*) exhibited potent inhibitory effects on the germination and growth of *Trifolium incarnatum*, *Silybum marianum*, and *Phalaris minor*. Similarly, Scavo et al. (2018) investigated the allelopathic potential of aqueous leaf extracts (40% and 80%) derived from Artichoke on seed germination and mean germination time of six weed species in Mediterranean agricultural environments. Their findings revealed varying effects based on the weed species and the concentration of the extracts. Notably, the aqueous leaf extracts significantly decreased the final percentage of seed germination for *A. myosuroides* (58.1%), *Diplotaxis erucoides* (43.9%), and *Portulaca oleracea* (42.5%) compared to the control group. Additionally, germination rate was observed to decline with increasing extract concentration. These studies underscore the potential of plant extracts as environmentally friendly alternatives for weed management in agriculture (Scavo *et al*., 2018). Gurmani et al. (2021) Research has shown that foliar application of leaf extracts from *Moringa oleifera*, *Parthenium hysterophorus*, and *Cannabis sativa* is highly effective in reducing leaf count, leaf length, and stem length of diverse weed species in corn and wheat fields (Gurmani *et al*., 2021). The leaf chlorophyll content and photosynthetic rate of weed plants notably decreased when exposed to the exogenous influence of leaf extracts.

The objective of this study is to investigate the impact of hydroalcoholic extracts derived from Papaver (*Papaver rhoeas*) fruits, Harmel (*Peganum harmala*) seeds, Fenugreek (*Trigonella foenum-graecum*) seeds, Pomegranate (*Punica granatum*) fruit skins, Juglans (*Juglans regia*) fruit skins, Peanut (*Arachis hypogea*) shoots, Camelina (*Camelina sativa*) shoots, and Artichoke (*Cynara scolymus*) leaves on the germinated seeds and seedling growth of *A. myosuroides* and *C. intybus* in laboratory and greenhouse settings. The study aims to identify the most potent and optimal concentrations of these extracts for effectively inhibiting the early growth of the target weed species.

2. Materials and methods

2.1. Preparation and collection of plant materials

Seeds of *C. intybus* and *A. myosuroides* were collected from the chickpea fields of the Campus of Agriculture and Natural Resources, Razi University, Kermanshah (34°19‘29“ N and 47°06’26“ E). Iran from mature plants, in the late spring and summer of 2022. Subsequently, the healthy and uniform seeds were carefully selected and stored and after-ripened at room temperature (18±2°C) until March of 2023 (Nolan, 1989; Holloway *et al*., 2024), marking the start of the experiment.

2.2. Preparation of plant extracts

Papaver fruits, Pomegranate and Juglans fruit skins, Peanut and Camelina shoots, and Artichoke leaves were collected from the agricultural fields and orchards of the Campus of Agriculture and Natural Resources, Razi University, located in Kermanshah, with geographic coordinates of 34°19‘29“ N and 47°06’26“ E. Harmel and Fenugreek seeds were acquired from PakanBazr Company. The hydroalcoholic extracts from mentioned plant materials were prepared using the methodology outlined by Falleh et al. (2013). Plant samples were individually washed with distilled water to remove impurities. Subsequently, each sample was stored in a dark environment at room temperature for 7 days. Following this, the samples were dried by placing them in an oven at 72 degrees Celsius for 48 hours and then ground to a fine powder. The powder obtained was homogenized by sieving it through a 35-mesh sieve. In the extract preparation process, a ratio of 1:10 of dry powder to 96% ethanol solvent was employed. The solutions were agitated on a shaker for 24 hours at 25 degrees Celsius. Subsequently, each extract underwent a double filtration process: initially through a four-layer cleaning cloth and then through Whatman filter paper number one to eliminate any residues. The ethanol was eliminated using a rotary evaporator at 45°C. The yield of crude plant extract was calculated as the ratio of the weight of the crude extract obtained after evaporation to the initial weight of the dry plant powder, expressed as a percentage (Equation 1) (Motmainna *et al*., 2021) (Table 1).

$$Yield\ of\ crude\ plant\ extract\ (\%) = \frac{Extract\ weight\ (g)}{Powder\ weight\ (g)} \times 100 \quad (1)$$

To safeguard the compounds and prevent degradation of allelochemical compounds, the extracts were stored in brown glass containers at 4°C in a refrigerator until the end of the experiments.

Table 1. The yield of crude plant extracts from the species used in the experiment

Number	Plant	Scientific name	Family	Plant organ	Yield of crude plant extract (%)
E1	Papaver	*Papaver rhoeas*	Papaveraceae	Fruit	11.99
E2	Artichoke	*Cynara scolymus*	Asteraceae	Leaves	38.46
E3	Pomegranate	*Punica granatum*	Punicaceae	Fruit skin	31.66
E4	Peanuts	*Arachis hypogea*	Fabaceae	Shoots	24.51
E5	Juglans	*Juglans regia*	Juglandaceae	Fruit skin	7.33
E6	Camelina	*Camelina sativa*	Brassicaceae	Shoots	12.50
E7	Fenugreek	*Trigonella foenumgraecum*	Fabaceae	Seed	6.66
E8	Harmel	*Peganum harmala*	Zygophyllaceae	Seed	6.22

To quantify the total alkaloid content, a 1 ml sample of plant extract was denatured with DMSO and mixed with 1 ml of 2 N HCl, followed by filtration. The resulting solution was then treated in a separatory funnel with 5 ml of each of bromocresol green solution and phosphate buffer. Sequential additions of chloroform (1, 2, 3, and 4 ml) were made, with thorough shaking after each addition. The final extract was diluted to 10 ml with chloroform in a volumetric flask. The absorbance was measured at a wavelength of 470 nm, and the results were expressed as milligrams of alkaloids per milliliter of extract (Lahare *et al*., 2021). To determine the total phenolic content, a mixture was prepared by mixing 1 ml of Folin-Ciocalteu reagent with 1 ml of plant extract, followed by the addition of 10 ml of a 7% sodium carbonate solution after a 5-minute delay. Gallic acid standards were prepared in concentrations between 20 and 100 $\mu g.ml^{-1}$. The mixture was allowed to stand at room temperature for 90 minutes before measuring the absorbance at 550 nm using a spectrophotometer. The results were expressed in terms of milligrams of gallic acid equivalent (GAE) per gram of dry extract weight (Lahare *et al*., 2021).

2.3. Laboratory study

A factorial experiment was carried out using a completely randomized design with three replications. The experiment involved factors including plant extracts (Papaver, Harmel, Fenugreek, Pomegranate, Juglans, Peanut, Camelina, and Artichoke) and extract concentrations (6.25, 12.5, 25, 50, 75, and 100 $g.l^{-1}$). Distilled water was considered as the negative control, while trifluralin 48% EC (W/V) (Treflan®) was used as the positive control at a recommended dose of 960 g $ai.ha^{-1}$. The test concentrations were prepared by first

creating stock solutions of the final extracts at 100% concentration, which were subsequently diluted with ethanol to achieve concentrations of 6.25, 12.5, 25, 50, 75, and 100 $g.l^{-1}$ of the extracts in a hydroalcoholic solution. Prior to the examination, seeds of two weed species, *C. intybus* and *A. myosuroides*, underwent sterilization in a 1% sodium hypochlorite solution for two minutes, followed by rinsing with distilled water.

In this study, seeds were germinated before applying various concentrations of extracts. This approach confirmed seed viability and established a standardized starting point for all seeds, thereby reducing variability in germination times and initial growth conditions. Additionally, trifluralin was included as a positive control because it is a pre-emergent herbicide that is absorbed by germinated seeds, enabling a direct comparison of its effects on growth alongside the plant extract treatments. By germinating the seeds prior to treatment application, a controlled environment was created, ensuring that any observed effects on growth could be confidently attributed to the essential oils or trifluralin rather than to variations in seed viability or dormancy. The seeds were placed in a sterilized closed container (20 cm in diameter) and soaked in 40 ml of distilled water at room temperature until the radicle tip emerged. Subsequently, 20 seeds were transferred to autoclaved petri dishes (9 cm in diameter), lined with two layers of Whatman filter paper, and 10 ml of each concentration of the plant extracts and control treatments was added to each petri dish. After applying the treatments, the petri dishes were sealed with parafilm. The Petri dishes were transferred to a growth chamber maintained at a temperature of 25°C with a photoperiod of 16 hours of light and 8 hours of darkness for 14 days (Verdugo-Navarrete *et al*., 2021). Subsequently, radicle and plumule lengths were measured using image processing techniques with JMicrovision software. The survival percentage was then calculated. The survival percentage, as described by Rastgoo et al. (2023), while the inhibition, as outlined by Khatun et al. (2023), was determined using Equations 2 and 3.

$$(2) \qquad Survival\ (\%) = \frac{A}{B} \times 100$$

Where A represents the number of viable seeds remaining at the end of the experiment, while B denotes the number of initial seeds at the start of the experiment.

$$(3) \qquad I = \frac{C - A}{C} \times 100$$

Where *I* is the inhibition value (%), *A* is the radicle length of the weed under the influence of plant extracts and *C* represents the length of the radicle in the control treatment.

2.4. Greenhouse study

The greenhouse test treatments included hydroalcoholic extracts obtained from Papaver fruits, Pomegranate fruit skins, Peanut shoots, and Artichoke leaves (identified as the most effective extracts in the laboratory study), in addition to glyphosate 41% SL (Roundup®) and distilled water considered as positive and negative controls, respectively. The weed seeds were initially soaked in autoclaved closed containers (20 cm in diameter), and once uniform seedlings had germinated, they were transplanted into plastic pots (20 cm in diameter) filled with 1.5 kg of sterilized soil collected from an untreated section of a field where herbicides had never been applied, located at Campus of Agriculture and Natural Resources, Razi University. The pots were then transferred to a greenhouse where the plants were maintained at a temperature range of 25±5 °C, with a relative humidity of about 65%, and subjected to a light cycle of 14 hours of light followed by 10 hours of darkness. Upon sprouting and growth, 10 seedlings displaying uniform growth were retained in each pot, while the remaining seedlings were removed. When the seedlings reached the stage of 3 to 5 leaves, different concentrations of plant extracts (25, 50, 75, and 100 $g.l^{-1}$), a positive control (equivalent to the recommended dose of glyphosate 1640 g $ai.ha^{-1}$), and a negative control were applied using a 1-liter sprayer with a spraying pressure of 1 bar and a flat fan nozzle type with a spray angle of 80 degrees (El-Mergawi and Al-Humaid, 2019).

Forty-eight hours following foliar spraying of *C. intybus* and *A. myosuroides* with the plant extracts at the mentioned concentrations, physiological traits including greenness (SPAD), stomatal conductance measured with a photosynthesizer (SD Portable model), and photosystem II quantum efficiency and photosynthetic efficiency were evaluated using a

chlorophyll fluorescence device (Pocket PEA model, manufactured in England). Two weeks after spraying, the entire plant, encompassing shoots and roots, was harvested. The procedure involved breaking the pots to thoroughly clean the roots and remove soil. Subsequently, the roots were separated from the shoots. Wet and dry weights of the shoots and roots were measured, and the heights of both shoot and root were determined using JMicrovision software. The inhibition percentage (I) was calculated utilizing Equation 4 (Możdżeń *et al*., 2021).

$$I = \frac{T - N}{N} \times 100 \quad (4)$$

Where T represents the Total dry weight of the control treatment and N represents the dry weight of the weed under the influence of plant extracts.

2.5. Statistical analysis

The statistical analyses of the data were done by analysis of variance (ANOVA-GLM) using R software. Prior to ANOVA, the normality of the data was assessed using the Shapiro-Wilk test. For variables with a significant Shapiro-Wilk test ($p \leq 0.05$), the data was transformed using appropriate methods (e.g., log transformation). A mean comparison between the treatments was performed using the Least Significant Difference (LSD) test at a significance level of $P \leq 0.05$. Visual representations of the data were generated using Excel software. Graphs included bar charts with error bars representing the standard error of the mean (SEM) for each treatment.

This investigation utilized two control treatments: distilled water and herbicide. A key goal was to assess how extract concentrations influenced outcomes relative to both baseline conditions (distilled water, representing no growth-limiting agent) and standard growth suppression (herbicide). To address this, a factorial design incorporating control treatments was implemented, enabling systematic evaluation of multiple variables while maintaining reference points through controlled comparisons (Marini, 2003). In the analysis of variance, the concentration effect was assessed alongside both control treatments. Conversely, the effects of extract type and its interaction with concentration were analyzed independently of the controls. The degrees of freedom in the ANOVA table were calculated accordingly.

It should be noted that:

- In the examination of survival percentage and inhibition percentage, Calculations referenced distilled water as the baseline, while only herbicide controls were included in the analyses.
- For morphological traits (plumule length, radicle length, stem length, root length, stem dry weight, and total dry weight) and physiological traits (SPAD, Stomatal Conductance, Pi, and Fv/Fm), Both distilled water and herbicide controls were incorporated into the analyses.

3. Results and discussion

3.1. Total phenolic and alkaloid content of the plant extracts

Artichoke exhibited the highest concentration of phenolic compounds, measuring. This was followed by Papaver, Peanut, Camelina, Harmel, Pomegranate, Walnut, and Fenugreek. Papaver, which had approximately 87.3%, 63.8%, 47.2%, 45.6%, 33.4%, 32.7%, 28.4% of the phenolic content of Artichoke, respectively (Fig. 1).

Papaver exhibited the highest total alkaloid content, measuring 29.65 µg ml^{-1}. This was followed by Fenugreek (7.39 µg ml^{-1}), which represented approximately 25% of Papaver's alkaloid content. Harmel contained 7.361 µg ml^{-1}, accounting for about 24.9% of Papaver's level. Pomegranate, Peanuts, Walnut, Artichoke, and Camelina had about 17.9%, 12.8%, 5.6%, 4.2%, and 0.5% of Papaver's level, respectively (Fig. 1).

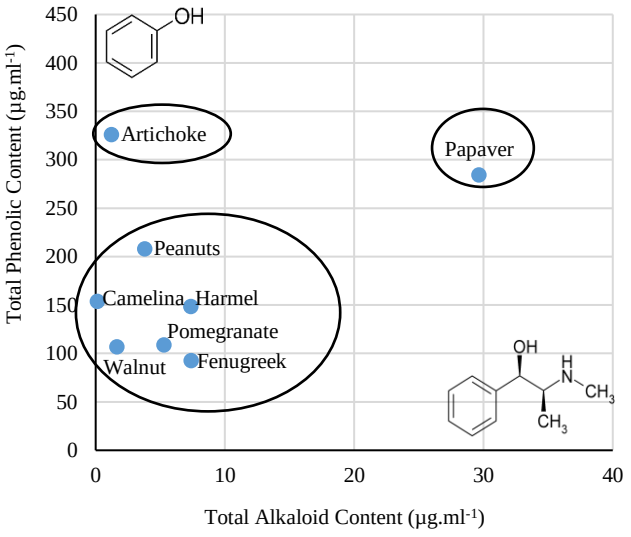

Figure 1. Total phenolic and alkaloid content of the eight studied plant extracts

3.2. Laboratory study

The findings presented in Table 2 indicate a significant variability in the influence of plant extract type and concentration on the inhibition percentage and survival rate of *C. intybus* and *A. myosuroides* weed species. The results indicate that Artichoke (*Cynara cardunculus* subsp. sylvestris) and Papaver extracts exhibited the highest inhibitory effect on the germinated seeds of *C. intybus*, while Harmel and Juglans extracts showed the lowest inhibition percentage. For *A. myosuroides*, the greatest inhibition of weed germinated seeds was achieved with Papaver, Artichoke, and Peanut extracts, with the lowest inhibition observed with Harmel extract (Fig. 2). The lowest survival percentage of *C. intybus* seedlings was obtained with the use of Papaver and Artichoke extracts, while the highest percentage was obtained with Harmel and Fenugreek extracts. Similarly, the highest percentage of *A. myosuroides* seedling survival was observed in Harmel extract (71.50%), with the lowest in Artichoke extract (26.61%), Papaver (28.05%), and Peanut (30.44%) (Table 3).

All concentrations of the tested plant extracts exhibited an inhibitory effect on the early growth and survival percentage of *C. intybus* and *A. myosuroides* seeds. The higher concentrations lead to greater inhibition (Table 3). At the highest concentration of 100 $g.l^{-1}$, *C. intybus* displayed a statistically significant inhibition on germinated seeds compared to the control group (distilled water). The impact of various plant extracts on *A. myosuroides* mirrored the effects observed on *C. intybus* seedling early growth. Notably, the most pronounced reduction in early growth of *A. myosuroides* occurred at a concentration of 100 $g.l^{-1}$, resulting in an impressive 89.81% reduction rate; the concentration of 6.25 $g.l^{-1}$ demonstrated the highest survival percentage among the tested concentrations. However, at the highest concentration of the extract (100 $g.l^{-1}$), there was a decrease in the survival percentage of *C. intybus* and *A. myosuroides* by 13.58% and 14.58%, respectively (Table 3).

Table 2. Variance analysis of the effect of different concentrations and source plant extract treatment on inhibition percentage and *Survival* percentage of *C. intybus* and *A. myosuroides* in laboratory conditions

Source of variation	df	Mean Square			
		C. intybus		*A. myosuroides*	
		Inhibition percentage	Survival percentage	Inhibition percentage	Survival percentage
Source plant (S)	7	7796^{***}	4801^{***}	3730^{***}	4529^{***}
Concentration (C)	6	8446^{***}	10398^{***}	13297^{***}	13872^{***}
S × C	35	44^{ns}	78^{ns}	96^{ns}	116^{ns}
Error	98	106	54	101	89
C.V. (%)	-	19.69	18.34	16.14	22.37

ns, *, **, and *** non-significant and significant at the probability levels of 5%, 1% and 0.1% respectively

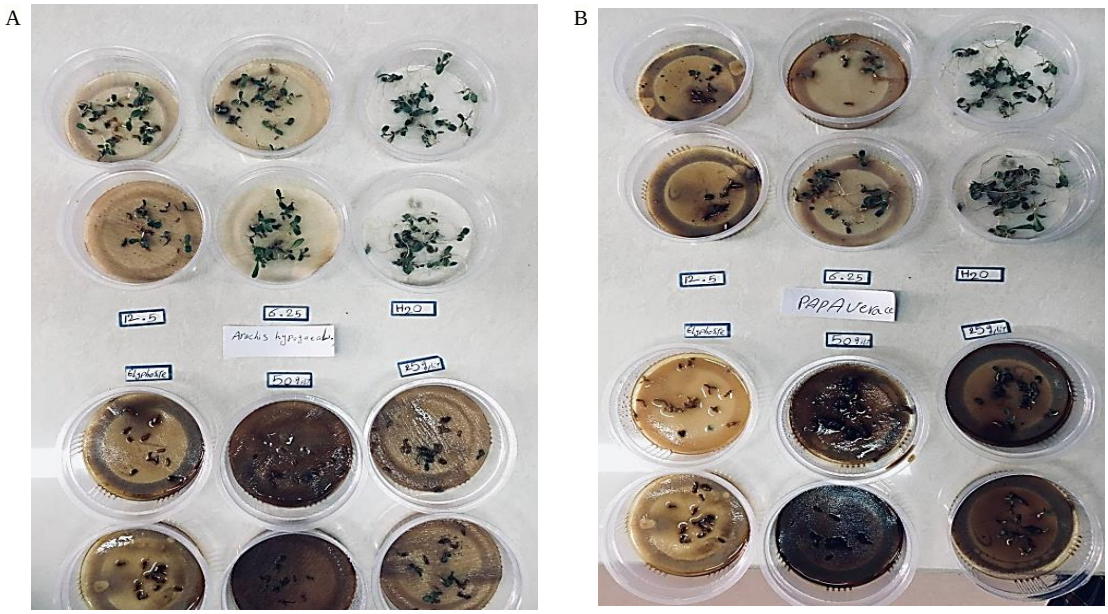

Figure 2. The effect of plant extracts of Papaver (A) and Peanut (B) at different concentrations on the inhibition percentage of *C. intybus* seeds germination in laboratory conditions

Table 3. Mean comparison simple effect of different concentrations and source plant extract treatment on inhibition percentage and survival percentage of *C. intybus* and *A. myosuroides* in laboratory conditions

Weeds	Property	*C. intybus*		*A. myosuroides*	
		Inhibition (%)	Survive (%)	Inhibition (%)	Survive (%)
Source plant	Artichoke	80.38±4.33^{a}	19.44±4.42^{d}	76.26±6.02^{a}	26.61±6.10^{e}
	Camelina	44.02±4.70^{d}	48.50±6.08^{b}	59.19±6.20^{bc}	46.11±7.94^{c}
	Fenugreek	34.79±4.58e	58.61±5.15^{a}	55.46±5.91^{c}	48.88±5.55^{c}
	Juglans	29.80±4.56^{e}	50.72±5.08^{b}	47.21±7.44^{d}	57.16±6.24^{b}
	Papaver	73.85±5.02^{ab}	19.77±4.31^{d}	77.68±5.28^{a}	28.05±6.31^{e}
	Peanuts	69.96±5.34^{b}	33.72±4.98^{c}	73.09±6.37^{a}	30.44±6.09^{de}
	Harmel	28.02±3.64^{e}	60.94±5.46^{a}	37.50±4.99^{e}	71.50±3.63^{a}
	Pomegranate	51.80±6.58^{c}	34.61±5.97^{c}	65.34±5.61^{b}	35.61±5.98^{d}
Concentration (g.L^{-1})	6.25	23.85±3.58^{f}	72.45±3.31^{a}	24.95±2.82^{f}	80.25±2.36^{a}
	12.5	36.15±4.27^{e}	57.83±4.16^{b}	41.73±3.85^{e}	63.95±3.52^{b}
	25	46.74±4.47^{d}	45.25±4.22^{c}	56.49±3.99^{d}	46.29±4.16^{c}
	50	57.44±4.77^{c}	33±3.73^{d}	72.62±3.75^{c}	32.04±4.10^{d}
	75	69.82±4.94^{b}	22.62±3.07^{e}	83.17±3.28^{b}	21.16±3.92^{e}
	100	75.46±4.68^{ab}	13.58±2.43^{f}	89.81±2.77^{a}	14.58±3.61^{f}
	Trifluralin	85.89±0.98^{a}	5.16±0.15^{f}	99.58±0.35^{a}	0.08±0.08^{g}

Different superscript letters indicate values significantly lower than the respective control ($P \leq 0.05$). Value mean ± standard error.

The plumule length of *C. intybus* treated with Harmel extract exhibited the highest growth, indicating the lowest inhibitory impact, while Papaver and Artichoke extracts demonstrated the most pronounced inhibition rates. Furthermore, the shortest radicle length was observed in seedlings treated with Artichoke and Papaver extracts. Regarding *A. myosuroides*, Fenugreek and Harmel extracts exhibited the highest plumule length**,** radicle length (least inhibitory effect), respectively, among the tested extracts. Conversely, *A. myosuroides* seeds treated with Papaver, Artichoke, and Peanut extracts displayed lowest plumule and radicle lengths, as well as lowest seedling weight, along with the highest inhibition rates (Tables 4 and 5). These findings suggest that Papaver, Artichoke, and Peanut extracts have the most pronounced inhibitory effects on the overall growth and development of *A. myosuroides* seedlings.

The plumule and radicle lengths of *C. intybus* and *A. myosuroides* decreased in response to increasing concentrations of extracts compared to the control. Specifically, the average length of *C. intybus* plumule decreased by 16.63 mm and 20.38 mm after treatment with extract concentrations of 100 g.l^{-1} and trifluralin, respectively, in comparison to distilled water application. Furthermore, the average radicle length of *C. intybus* decreased by 29.91 mm and 34.25 mm following treatment with extract concentrations of 100 g.l^{-1} and trifluralin, respectively, compared to distilled water treatment. Similarly, the concentration of the extract at 100 g.l^{-1}, along with the herbicide trifluralin, resulted in increased plumule lengths (33.67 and 37.12 mm) and radicle lengths (44.50 and 49.48 mm) of *A. myosuroides* compared to distilled water. Following the distilled water treatment, the extract concentration of 6.25 g.l^{-1} exhibited the greatest plumule and radicle lengths in both *C. intybus* and *A. myosuroides* (Table 5). These findings underscore the diverse effects of different extracts and herbicides on plant growth parameters, underscoring the importance of understanding these effects for the development of effective weed management strategies (Table 5).

This study identified phenolic and alkaloid compounds in all eight types of plant extracts analyzed. Previous research has shown that phenols are key allelochemicals, known for their potent inhibitory effects on germination and growth (Patanè *et al*., 2023). Phenolic compounds are known to induce the production of Reactive Oxygen Species (ROS) and inhibit the production of detoxification enzymes and growth hormones. They can also impact the photochemistry of photosystem II, disrupting electron transfer and the production of ATP and NADPH (Tucuch-Pérez *et al*., 2023). Allelochemicals, particularly phenols, can decrease cell membrane permeability, affect gibberellin hormone activity, and inhibit it. The inhibition of gibberellin may disrupt cell division in meristem tissue, preventing stem internode elongation (Erida *et al*., 2019).

The effect of plant secondary compounds on weed species varies significantly due to differences in allelopathic compounds, their concentrations, and

allelochemical properties present in plant species extracts (Krumsri *et al*., 2022). In the experiment conducted, the phytotoxicity of the extracts on *C. intybus* and *A. myosuroides* increased with increasing concentration, with the concentrations of 100 and 75 $g.l^{-1}$ exhibiting the greatest inhibitory effect. This concentration-dependent inhibitory activity is consistent with the findings of other researchers who have documented similar effects using various plant extracts (Hossen *et al*., 2020; Islam *et al*., 2019; Rob *et al*., 2021; Zaman *et al*., 2021). The inhibitory effects of plant extracts on weed growth are indicative of the presence of phytotoxic compounds. In this study, the hydroalcoholic extract of Artichoke leaf, as well as Papaver fruit, exhibited the highest herbicidal activity. These extracts significantly reduced seedling early growth and photosynthetic activities of weed species under both laboratory and greenhouse conditions. Seed early growth is a critical stage in plant growth, as it directly affects plant survival and development. The inhibitory effect of plant extracts on weed seed germination is likely attributed to allelopathic chemicals that hinder seed germination by interfering with cell division, disrupting energy transfer mechanisms, and restricting water and nutrient absorption (Popoola *et al*., 2020). Allelopathic compounds can induce changes in pH, alter the osmotic capacity of seedlings, cause cell damage, affect membrane permeability, reduce mineral absorption, and diminish water absorption by roots. These effects collectively contribute to a decrease in stem growth (Siyar *et al*., 2019). In addition, the reduction in growth may be attributed to the presence of allelochemical compounds in the extracts. These compounds can prevent hormonal activity, thereby leading to a decrease in cell division and elongation in the apical regions of the stem and root (Erida *et al*., 2019).

Table 4. Variance analysis of the effect of different concentrations and source plant extract treatment on growth traits of *C. intybus* and *A. myosuroides* in laboratory conditions

Source of variation	df	Mean Square			
		C. intybus		*A. myosuroides*	
		Plumule length	Radicle length	Plumule length	Radicle length
Source plant (S)	7	425.4***	1321.8***	311.4***	906***
Concentration (C)	7	428.1***	1324.4***	1957.5***	3175***
S × C	35	3.7^{ns}	6.4^{ns}	8.9^{ns}	18^{ns}
Error	100	4.4	20.9	13.8	29
C.V. (%)	-	18.55	23.34	26.49	27.93

ns, *, **, and *** non-significant and significant at the probability levels of 5%, 1% and 0.1% respectively

Table 5. Mean comparison simple effect of different concentrations and source plant extract treatment on growth traits of *C. intybus* and *A. myosuroides* in laboratory conditions

Weeds	Property	*C. intybus*		*A. myosuroides*	
		Plumule length (mm)	Radicle length (mm)	Plumule length (mm)	Radicle length (mm)
Source plant	Artichoke	5.05±1.34^{e}	7.66±1.69^{e}	9.33±2.49^{d}	11.94±3.02^{e}
	Camelina	15.27±1.21^{b}	22.83±1.96^{b}	13.33±2.29^{c}	20.50±3.13^{bc}
	Fenugreek	14.72±0.95^{b}	26.61±1.93^{a}	20.77±2.03^{a}	22.33±2.98^{b}
	Juglans	14.61±0.96^{b}	28.16±1.90^{a}	15.88±2.21^{b}	23.38±3.44^{b}
	Papaver	4.83±0.88^{e}	10.45d±2.00^{e}	9.72±2.28^{d}	11.11±2.65^{e}
	Peanuts	7.72±1.23^{d}	11.50±2.04^{d}	10.38±2.54^{d}	13.72±3.24^{de}
	Harmel	17.05±0.73^{a}	29.05±1.51^{a}	18.16±2.02^{b}	32.27±2.58^{a}
	Pomegranate	10.83±1.27^{c}	19.33±2.71^{c}	13.05±2.59^{c}	17.11±2.75^{cd}
Concentration ($g.L^{-1}$)	Distilled	22.54±0.27^{a}	39.87±0.61^{a}	37.12±0.95^{a}	49.58±0.67^{a}
	6.25	17.79±0.91^{b}	30.45±1.54^{b}	28.75±0.80^{b}	37.12±1.46^{b}
	12.5	14.5±0.07^{c}	25.58±1.80^{c}	21.16±1.05^{c}	28.75±1.90^{c}
	25	12.20±1.07^{d}	21.37±1.87^{d}	15.20±1.12^{d}	21.37±1.92^{d}
	50	9.5±1.10^{e}	17.12±1.98^{e}	8.91±1.24^{e}	13.58±1.90^{e}
	75	7.66±1.06^{f}	12.20±2.03^{f}	5.5±1.20^{f}	8.37±1.67^{f}
	100	5.91±0.96^{g}	9.96±1.92^{fg}	3.45±0.98^{fg}	5.08±1.41^{g}
	Trifluralin	2.16±0.04^{h}	5.62±0.04^{g}	0±0^{g}	0.10±0.07^{g}

Different superscript letters indicate values significantly lower than the respective control ($P \leq 0.05$). Value mean ± standard error.

3.3. Greenhouse study

3.3.1. Growth inhibition

After conducting experiments in the laboratory, plants with extracts demonstrating higher deterrence were chosen for foliar spraying in greenhouse conditions on weed seedlings. The most notable inhibitory effects on *A. myosuroides* growth were observed with the foliar application of Artichoke extract (57.16%), followed closely by Papaver extract (50.25%) (Tables 6 and 7). Similarly, for *C. intybus*, Artichoke extract exhibited the highest inhibition rate at 55.88%, with Papaver extract showing a slightly

lower inhibition rate of 53.30%. Notably, among the treatments, the use of Pomegranate fruit skin extract resulted in the lowest inhibition rate on the studied weeds (Table 7). Furthermore, the application of the highest extract concentration (100 $g.l^{-1}$) and glyphosate herbicide effectively halted the growth of both *C. intybus* and *A. myosuroides* by over 50%. Notably, the 100 $g.l^{-1}$ concentration of both the extract and glyphosate herbicide demonstrated the most significant inhibitory effect on the growth of *C. intybus* and *A. myosuroides* seedlings. The 100 $g.l^{-1}$ extract concentration showed no significant difference in inhibition compared to glyphosate herbicide. Conversely, the lowest inhibitory rate was observed at the extract concentration of 25 $g.l^{-1}$ for both *C. intybus* and *A. myosuroides* (Tables 6 and 7).

Table 6. Variance analysis of the effect of different concentrations and source plant extract treatment on the growth inhibition percentage of *C. intybus* and *A. myosuroides* in greenhouse conditions.

Source of variation	df	Mean Square	
		C. intybus	*A. myosuroides*
		Inhibition Percentage	Inhibition Percentage
Source plant (S)	3	958.9^{***}	1548^{***}
Concentration (C)	4	3089.8^{***}	3002.6^{***}
S × C	9	196.5^{ns}	79.8^{ns}
Error	34	92.6	139
C.V. (%)	-	20.22	24.54

ns, *, **, and *** non-significant and significant at the probability levels of 5%, 1% and 0.1% respectively

Table 7. Mean comparison of simple effect of different concentrations and source plant extract treatment on the growth inhibition percentage of *C. intybus* and *A. myosuroides* in greenhouse conditions

Weeds	Property	*C. intybus*	*A. myosuroides*
		Inhibition (%)	Inhibition (%)
Source plant	Artichoke	55.88 ± 7.32^{a}	57.16 ± 6.06^{a}
	Papaver	53.30 ± 6.09^{a}	50.25 ± 4.71^{a}
	Peanuts	40.41 ± 3.86^{b}	34.16 ± 4.31^{b}
	Pomegranate	38.19 ± 4.59^{b}	35.16 ± 5.53^{b}
Concentration ($g.L^{-1}$)	25	25.30 ± 2.40^{d}	27.91 ± 3.01^{c}
	50	42.01 ± 2.95^{c}	36 ± 3.26^{c}
	75	51.39 ± 3.50^{b}	49.08 ± 5.08^{b}
	100	57.67 ± 5.95^{ab}	63.75 ± 5.54^{a}
	Glyphosate	69.08 ± 5.52^{a}	77.58 ± 1.37^{a}

Different superscript letters indicate values significantly lower than the respective control ($P\leq0.05$). Value mean ± standard error.

Foliar spraying of Artichoke and Papaver extracts led to a significant decrease in root length, stem length, root dry weight, and total dry weight in *C. intybus* and *A. myosuroides* compared to Pomegranate and Peanut extracts (Tables 8 and 9).

Table 8. Variance analysis of the effect of different concentrations and source plant extract treatment on the growth traits of *C. intybus* in greenhouse conditions

Source of variation	df	Mean Square			
		Stem length	Root length	Root dry weight	Total dry weight
Source plant (S)	3	2454^{***}	2515.4^{***}	0.0679^{***}	0.039^{**}
Concentration (C)	5	2179.9^{***}	2872.8^{***}	0.0535^{***}	0.226^{***}
S × C	9	33^{ns}	17.7^{ns}	0.0005^{ns}	0.004^{ns}
Error	36	56.2	84.4	0.006	0.006
C.V. (%)	-	8.73	14.78	25.22	17.49

ns, *, **, and *** non-significant and significant at the probability levels of 5%, 1% and 0.1% respectively

Table 9. Variance analysis of the effect of different concentrations and source plant extract treatment on the growth traits of *A. myosuroides* in greenhouse conditions

Source of variation	df	Mean Square			
		Stem length	Root length	Root dry weight	Total dry weight
Source plant (S)	3	1789^{**}	721.3^{***}	0.0192^{***}	$0.013^{**.}$
Concentration (C)	5	6638^{***}	1006.5^{***}	0.0152^{***}	0.056^{***}
S × C	9	169^{ns}	8.2^{ns}	0.0006^{ns}	0.002^{ns}
Error	36	332	32	0.0005	0.002
C.V. (%)	-	12.45	5.19	12.86	13.37

ns, *, **, and *** non-significant and significant at the probability levels of 5%, 1% and 0.1% respectively.

Among the studied extracts, the use of Artichoke extract followed by Papaver extract had the most pronounced inhibitory effects on the measured growth parameters of the target weed species. In comparison to Pomegranate extract, the application of Artichoke and Papaver extracts resulted in notable reductions in *C. intybus* stem length (31.81% and 21.01% respectively), root length (42.40% and 31.66% respectively), root dry weight (46.15% and 33.33% respectively), and total dry weight (21.56% and 17.64% respectively) (Table 10). The shortest *A. myosuroides* stem and the highest inhibition were observed in the Artichoke extract treatment, with a 17.63% reduction in stem length compared to Pomegranate extract. Furthermore, foliar spraying of *A. myosuroides* seedlings with Papaver and Artichoke extracts resulted in a significant reduction in seedling dry weight by 21.62% and 16.21%, respectively, compared to Peanut extract. These findings underscore the varying effects of different plant extracts on the growth characteristics of *A. myosuroides* weed and emphasize the potential for utilizing specific extracts to achieve targeted outcomes in weed management strategies (Table 10).

The extracts concentrations of 100 and 75 $g.l^{-1}$, along with the recommended concentration of glyphosate herbicide, significantly reduced both the stem and root

length of *C. intybus* (Table 8). Specifically, the treatment with 100 g.l^{-1} extract concentration and glyphosate resulted in a 52.76% and 49.58% decrease in stem length of *C. intybus* seedlings, respectively, compared to the control. Moreover, the shortest root length was observed in the 100 g.l^{-1} extract concentration treatment, followed by glyphosate and the 75 g.l^{-1} extract concentration, which exhibited reductions of 56.73%, 56.12%, and 51.58%, respectively, compared to the control (Table 11). There was no significant difference between the effects of the extract at a concentration of 100 g.l^{-1} and glyphosate herbicide on both stem and root length (Table 11). There was a significant decrease in *A. myosuroides* root dry weight and total dry weight at the highest extract concentration (100 g.l^{-1}) (Table 11).

Table 10. Mean comparison simple effect of source plant extract treatment on the growth traits of *C. intybus* and *A. myosuroides* in greenhouse conditions

Weeds	Property	Artichoke	Papaver	Peanuts	Pomegranate
C. intybus	Stem length (mm)	67.33±8.14^{c}	78±9.25^{b}	93.08±6.96^{a}	98.75±7.27^{a}
	Root length (mm)	44.25±8.29^{d}	52.5±8.44^{c}	66.41±9.96^{b}	76.83±7.68^{a}
	Root dry weight (g)	0.21±0.01^{c}	0.26±0.01^{bc}	0.31±0.01^{b}	0.39±0.03^{a}
	Total dry weight (g)	0.4±0.05^{b}	0.42±0.03^{b}	0.50±0.03^{a}	0.51±0.03^{a}
A. myosuroides	Stem length (mm)	128.08±8.28^{b}	146.33±9.93^{a}	152.08±6.90^{a}	155.5±5.76^{a}
	Root length (mm)	99±2.50^{c}	104±2.67^{b}	115.58±3.001^{a}	113.08±3.08^{a}
	Root dry weight (g)	0.13±0.01^{d}	0.16±0.01^{c}	0.19±0.005^{b}	0.22±0.01^{a}
	Total dry weight (g)	0.31±0.03^{bc}	0.29±0.01^{bc}	0.37±0.02^{a}	0.33±0.01^{b}

Different superscript letters indicate values significantly lower than the respective control ($P \leq 0.05$). Value mean ± standard error.

Table 11. Mean comparison simple effect of different concentrations of plant extract treatment on the growth traits of *C. intybus* and *A. myosuroides* in greenhouse conditions

Weeds	Property	Distilled	25 g.L^{-1}	50 g.L^{-1}	75 g.L^{-1}	100 g.L^{-1}	Glyphosate
C. intybus	Stem length (mm)	122.66±3.04^{a}	99.83±6.90^{b}	88.83±9.17^{c}	79.5±8.34^{d}	69±9.29^{e}	73.08±4.60^{de}
	Root length (mm)	110.16±0.71^{a}	78.91±7.83^{b}	60.08±9.15^{c}	53.33±9.63^{cd}	47.66±9.35^{d}	48.33±0.22^{cd}
	Root dry weight (g)	0.53±0.05^{a}	0.35±0.03^{b}	0.31±0.02^{bc}	0.28±0.02^{cd}	0.23±0.02^{d}	0.25±0.01^{cd}
	Total dry weight (g)	0.85±0.10^{a}	0.63±0.02^{b}	0.48±0.01^{c}	0.41±0.02^{d}	0.31±0.02^{e}	0.35±0.01^{de}
A. myosuroides	Stem length (mm)	200±2.51^{a}	175±4.33^{b}	151.25±5.91^{c}	134.5±6.85^{d}	121.25±6.44^{de}	104.83±0.54^{e}
	Root length (mm)	132.75±44^{a}	119.91±2.74^{b}	109.5±2.41^{c}	103.5±2.48^{d}	98.75±2.46^{e}	99.25±0.38^{de}
	Root dry weight (g)	0.27±0.005^{a}	0.22±0.009^{b}	0.19±0.01^{c}	0.16±0.01^{d}	0.14±0.01^{e}	0.13±0.011^{e}
	Total dry weight (g)	0.51±0.008^{a}	0.42±0.02^{b}	0.34±0.01^{c}	0.29±0.01^{d}	0.26±0.01^{e}	0.27±0.002^{de}

Different superscript letters indicate values significantly lower than the respective control ($P \leq 0.05$). Value mean ± standard error.

3.3.2. Degree of greenness

The SPAD device measures the greenness of a plant by determining the chlorophyll content of the leaves, where higher values indicate higher chlorophyll content and therefore greater greenness (Table 12). Foliar spraying of extracts affected SPAD measurements in *C. intybus* and *A. myosuroides*. Pomegranate extract had the least inhibitory effect, while Artichoke extract caused significant reductions, decreasing SPAD measurements by 39.62% for *C. intybus* and 46.75% for *A. myosuroides*, indicating a marked decline in chlorophyll content. (Table 13).

Table 12. Variance analysis of the effect of different concentrations and source plant extract treatment on the photosynthetic traits of *C. intybus* and *A. myosuroides* in greenhouse conditions

Source of variation	df	Mean Square							
		C. intybus				*A. myosuroides*			
		SPAD	gs	Pi	Fv/Fm	SPAD	gs	Pi	Fv/Fm
Source plant (S)	3	156.9***	232.7***	694.5***	0.283***	71.3**	738.3***	527.7***	0.23***
Concentration (C)	5	1125.3***	701.2***	525***	0.131***	432.7***	1140.4***	318.5***	0.16***
S × C	9	1.7^{ns}	2^{ns}	9.2^{ns}	0.0190***	2.8^{ns}	17*	9.8^{ns}	0.014^{ns}
Error	36	12.6	8.8	6.1	0.004	3.1	7.1	22.2	0.011
C.V. (%)	-	20.09	18.26	16.85	10.60	18.28	14.45	17.95	17.44

ns, *, **, and *** non-significant and significant at the probability levels of 5%, 1% and 0.1% respectively. gs: Stomatal conductance, Pi: photosynthetic efficiency and Fv/Fm: photosystem II quantum efficiency

Table 13. Mean comparison simple effect of source plant extract treatment on the photosynthetic traits of *C. intybus* and *A. myosuroides* in greenhouse conditions

Weeds	Property	Artichoke	Papaver	Peanuts	Pomegranate
C. intybus	SPAD	12.13±2.89^{c}	17.12±3.00^{b}	19.47±2.87^{ab}	20.09±2.77^{a}
	gs	10.46±2.07^{d}	13.17±1.81^{c}	16.98±2.20^{b}	20.54±1.97^{a}
	Pi	6.28±1.11^{c}	8.75±1.17^{b}	20.36±2.06^{a}	20.78±1.84^{a}
A. myosuroides	SPAD	6.15±1.67^{c}	8.62±1.67^{b}	10.83±1.85^{a}	11.55±1.77^{a}
	Pi	4.19±1.82^{b}	4.55±1.14^{b}	13.63±1.97^{a}	13.34±2.39^{a}
	Fv/Fm	0.45±0.05^{b}	0.51±0.07^{b}	0.72±0.02^{a}	0.72±0.01^{a}

Different superscript letters indicate values significantly lower than the respective control ($P \leq 0.05$). Value mean ± standard error. gs: Stomatal conductance

The greenhouse experiment results demonstrated a significant decrease in greenness levels with increasing extract concentrations for both plant species. All extract concentrations exhibited a notable difference compared to distilled water. Notably, using an extract concentration of 100 g.l^{-1} resulted in the lowest greenness levels, with no significant difference compared to glyphosate.

Specifically, foliar spraying with an extract concentration of 100 g.l^{-1} and glyphosate resulted in SPAD measurements of 81.43% and 86.59% for *C. intybus* and 91.29% and 91.12% for *A. myosuroides*, respectively, compared to distilled water (Table 14). These findings highlight the efficacy of specific extract concentrations in reducing chlorophyll content in studied weeds.

Table 14. Mean comparison simple effect of different concentrations of plant extract treatment on the photosynthetic traits of *C. intybus* and *A. myosuroides* in greenhouse conditions

Weeds	Property	Distilled	25 g.L^{-1}	50 g.L^{-1}	75 g.L^{-1}	100 g.L^{-1}	Glyphosate
C. intybus	SPAD	37.66±0.16^{a}	30.75±1.3^{b}	19.7±1.44^{c}	11.37±1.30^{d}	6.99±1.21^{e}	5.05±0.24^{e}
	gs	38.47±0.60^{a}	24.9±1.28^{b}	15.89±1.43^{c}	12.13±1.39^{d}	8.24±1.46^{e}	9.14±0.26^{de}
	Pi	34.81±0.33^{a}	20.73±2.57^{b}	15.90±2.19^{c}	11.16±1.85^{d}	8.39±1.78^{e}	4.20±0.50^{f}
A. myosuroides	SPAD	22.62±0.51^{a}	16.55±0.83^{b}	12.22±0.88^{c}	6.41±0.93^{d}	1.97±0.54^{e}	2.008±0.22^{e}
	Pi	31.67±0.70^{a}	15.52±2.49^{b}	10.49±2.005^{c}	6.26±1.54^{d}	3.44±1.28^{d}	2.28±0.22^{d}
	Fv/Fm	0.84±0.001^{a}	0.73±0.02^{ab}	0.68±0.02^{bc}	0.56±0.5^{d}	0.43±0.07^{e}	0.59±0.009^{cd}

Different superscript letters indicate values significantly lower than the respective control ($P \leq 0.05$). Value mean ± standard error. gs: Stomatal conductance, Pi: photosynthetic efficiency and Fv/Fm: photosystem II quantum efficiency

3.3.3. Stomatal conductance

The type of extracts and their concentrations had a significant impact on the stomatal conductance of *C. intybus* leaves. In contrast, the stomatal conductance of *A. myosuroides* leaves was impacted by the interaction between the extracts and their concentrations (Fig. 3). Artichoke extract exhibited the lowest stomatal conductivity for *C. intybus*, demonstrating reductions of 10.08, 6.52, and 1.71 mmol $CO_2.m^{-2}.s^{-1}$ compared to Pomegranate, Peanut, and Papaver extracts, respectively (Table 13). Furthermore, extract concentration of 100 g.l^{-1} and the recommended dose of glyphosate led to a substantial decrease of 78.58% and 76.25% in stomatal conductance compared to distilled water treatment (Table 14). In the case of *A. myosuroides*, the lowest stomatal conductance was observed with Artichoke and Papaver extracts at concentrations of 100 g.l^{-1} and 75 g.l^{-1}, respectively. These extracts resulted in significant reductions of 98.24% and 95% for Artichoke extract, and 96.50% and 83.23% for Papaver extract, compared to distilled water. Furthermore, glyphosate herbicide treatment significantly reduced leaf stomatal conductance by 91.44% compared to distilled water. Interestingly, the highest stomatal conductance was recorded with distilled water treatment (42.06 mmol $CO_2.m^{-2}.s^{-1}$), followed by Pomegranate extract at a concentration of 25 g.l^{-1} (35.55 mmol $CO_2.m^{-2}.s^{-1}$), which was statistically similar to Peanut extract at the same concentration (Fig. 3).

3.3.4. Photosynthetic efficiency index (Pi)

Application of Artichoke and Papaver extracts resulted in the lowest photosynthetic efficiency for both *C. intybus* and *A. myosuroides*. Specifically, compared to the use of Pomegranate extract, Artichoke extract significantly reduced the photosynthetic efficiency of *C. intybus* leaves by 69.77% and *A. myosuroides* by 57.89%, while Papaver extract decreased the efficiency of *C. intybus* by 68.59% and *A. myosuroides* by 65.89% (Table 13). These findings underscore the significant impact of different plant

extracts on the photosynthetic processes of these weed species.

The comparison of the averages revealed that the concentration of 25 g.l^{-1} of the extract exhibited lower photosynthetic efficiency in *C. intybus* and *A. myosuroides* compared to other extract concentrations in greenhouse conditions. Furthermore, both weed species displayed reduced photosynthetic efficiency with the glyphosate and subsequently with the 100 g.l^{-1} concentration, showing the lowest efficiency levels. All extract concentrations significantly differed from distilled water and decreased photosynthetic efficiency in both weed species. Interestingly, the effects of the 75 g.l^{-1} and 100 g.l^{-1} concentrations on photosynthetic efficiency in *A. myosuroides* weed demonstrated improved performance, nearly matching that of the herbicide, with no significant difference observed (Table 14).

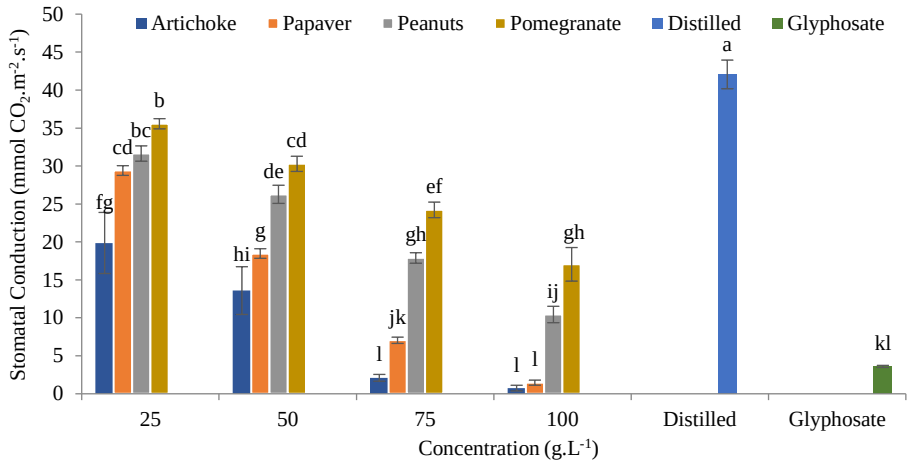

Figure 3. Mean comparison of the interaction effect of different concentrations and source plant extract treatment on the stomatal conduction of *A. myosuroides* in greenhouse conditions. Different superscript letters indicate values significantly lower than the respective control (P ≤0.05). Value mean ± standard error.

3.3.5. Quantum efficiency of photosystem II

Artichoke and Papaver treatments had the most significant effect on photosystem II quantum efficiency (Fig. 4). In contrast, Peanut and Pomegranate extracts resulted in the highest photosystem II quantum efficiency for both weed species, which showed the least impact on this trait. When *A. myosuroides* were treated with Artichoke extract, they exhibited the lowest quantum efficiency of photosystem II, showing reductions of 37.50% compared to Pomegranate extract (Table 13).

With a concentration of 100 g.l^{-1} followed by glyphosate herbicide the most pronounced impact on the quantum efficiency of photosystem II was observed. These treatments led to reductions in the quantum efficiency of photosystem II in *A. myosuroides* by 48.80% and 29.76% respectively (Table 14).

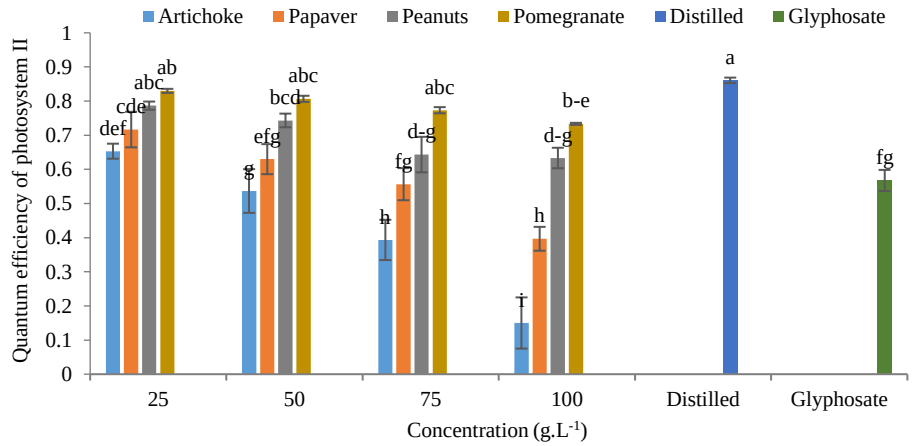

Figure 4. Mean comparison of the interaction effect of different concentrations and source plant extract treatment on the quantum efficiency of photosystem II of C. intybus in greenhouse conditions. Different superscript letters indicate values significantly lower than the respective control (P ≤0.05). Value mean ± standard error.

In the present study, the dry weight of roots and whole seedlings of both *C. intybus* and *A. myosuroides* weed species was observed to decrease following treatment with extracts from different plant species. This reduction in biomass can be attributed to a decrease in photosynthetic activity within the seedlings. Additionally, shorter root and stem lengths may contribute to a decrease in both the wet and dry weight of the shoots and roots. The decrease in biomass production induced by plant extracts is likely a result of disrupted cell division and photosynthetic activity, which can be linked to the depletion of chlorophyll content (Hayyat *et al*., 2020). This reduction can be attributed to the activation of enzymes involved in metabolic transformations by allelochemical compounds, which may lead to altered metabolic pathways and subsequent changes in biomass production (Możdżeń *et al*., 2021).

In the present study, foliar application of plant extracts significantly decreased SPAD, stomatal conductance, photosynthesis rate, and PSII quantum efficiency in both weed species. This reduction is likely attributed to the decrease in active components of key photosynthetic enzymes under the influence of allelochemicals. These allelochemicals disrupt the synthesis of various chloroplast pigments in seedling leaves, leading to the observed effects on physiological parameters (Uyun *et al*., 2024). Photosynthesis is the fundamental process by which light energy is absorbed and converted into organic matter in the presence of green plant pigments. The role of plant pigments as mediators in this process is crucial, as they facilitate the absorption and utilization of light energy by photosynthetic organisms (Bashar *et al*., 2022).

On the other hand, this may be attributed to the destruction of the layered structure of the chloroplast by allelochemicals, which can inhibit the expression of photosynthesis genes in plant cells. This inhibition can suppress the formation of chlorophyll, thereby weakening the rate of photosynthesis and reducing the oxygen absorption capacity of plants, including hydroponic plants (Li *et al*., 2021). The reduction of leaf photosynthesis has been attributed to decreased carboxylation efficiency, alterations in photosynthetic metabolites, chloroplast disruption, and heightened enzyme activity in plants, which collectively contribute to the impairment of photosynthetic processes (Huihui *et al*., 2020). On the other hand, it has been reported that allelochemicals can affect the photosynthesis rate of seedling leaves by altering stomatal factors, including stomatal conductance and intracellular CO_2 levels, which can impact photosynthetic efficiency (Wang *et al*., 2022).

Consistent with the findings of our study, Nafees et al. (2021) reported that the growth parameters of mung bean (*Vigna radiata*), such as radicle and plumule elongation, seed growth, wet and dry weight, and chlorophyll content of the experimental product, were significantly improved using extract *Helianthus annuus*. In another study, sunflower aqueous extracts showed a notable inhibitory effect on chickpea SPAD measurements. The root extract exhibited the most potent allelochemical impact on the physiological characteristics of chickpeas. Furthermore, leaf and stem extracts at a concentration of 25% displayed stimulatory effects on chickpea growth. However, concentrations of 50% and 75% exhibited inhibitory effects on the rate of photosynthesis, water use efficiency, and stomatal conductance in chickpeas (Janusauskaite, 2023).

4. Conclusion

The results obtained in the present study demonstrate that all the extracts utilized in laboratory and greenhouse conditions exhibited significantly distinct inhibitory effects on the early growth and photosynthetic parameters of *C. intybus* and *A. myosuroides*. The most substantial reduction in radicle and plumule elongation, seedling growth and photosynthetic processes was observed with the hydroalcoholic extract of Artichoke leaves and Papaver fruit, which had highest total phenolic and alkaloid content. These findings suggest that the tested plant extracts possess potent allelopathic properties, which can be effectively utilized for weed management in agricultural systems. According to the results of this research, concentrations of 100 and 75 $g.l^{-1}$ showed the most effective inhibitory effect on radicle and plumule elongation in laboratory, as well as, stem and root length, root dry weight, overall seedling weight, greenness level, and photosynthetic parameters of the weeds in greenhouse settings. Furthermore, the inhibitory effects observed in most traits were comparable to those achieved with trifluralin and glyphosate herbicides. The concentration-dependent inhibitory effects observed in this study highlight the

potential of these extracts as natural and eco-friendly alternatives to synthetic herbicides.

Conflict of interests

No potential conflict of interest was reported by the author(s).

Ethics approval and consent to participate

No humans or animals were used in the present research. The authors have adhered to ethical standards, including avoiding plagiarism, data fabrication, and double publication.

Consent for publications

All authors read and approved the final manuscript for publication.

Availability of data and material

All the data are embedded in the manuscript.

Authors' contributions

Methodology; review and editing; supervision; validation. Bita Abbasi: Data collection; investigation; data analysis; writing original draft. Mahshid Rahimi Fard: Laboratory analyze assistant; review and editing; advisory support and Golamreza Mohammadi: Review and editing.

Informed consent

The authors declare not to use any patients in this research.

Funding/Support

This study was supported by Razi University, Kermanshah, Iran.

Acknowledgement

I would like to express my gratitude to the Razi University for providing the resources and support necessary for this research.

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HOW TO CITE THIS ARTICLE

Abbasi B., Bagheri A., Rahimifard M., Mohammadi G. 2026. Effects of Various Plant Extracts on the Seedling Development of *Cichorium intybus* and *Alopecurus myosuroides*. *Agrotechniques in Industrial Crops* 6(1): 49-64. 10.22126/ATIC.2026.11555.1184