



Allelopathic Potential of Licorice (*Glycyrrhiza glabra* L.) on Germination, Growth, Chlorophyll Content and Yield of Some Crop and Weed Plants

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Abstract

Allelopathy is a biological phenomenon that can be used to reduce weed growth by using crops that have an allelopathic effect. Therefore, we have been determined to investigate the impact of licorice (*Glycyrrhiza glabra* L.) aqueous extract spraying on wheat, barley, cephalaria, and white mustard plants on chlorophyll content and biological yield in the plastic house from December 30th, 2024, to April 24th, 2025, at Grdarasha Research Field, College of Agricultural Engineering Sciences. For the aqueous extracts, five concentrations were used: 0,25,50,75, and 100%, with three replicates and a completely randomized design (CRD) used. Finding significant differences between plant species for all parameters, the aqueous extract at 50 and 75% concentrations gives the highest weed control efficiency in this study. Also, for the interaction between treatments, they found that chlorophyll content significantly increased in white mustard at 50%, 75%, and 100% licorice root extract. Biological yield recorded the highest production in wheat, with 25%. The response ratio significantly increased in the Cephalaria plant to 67.85% from 100% and decreased in white mustard by 67.58% to 50%. In contrast, the inhibition ratio significantly increases to 64.58% for white mustard and 50%, and this rate is a 64.58% decline in cephalaria plants with 100% licorice extract. A laboratory experiment using a completely randomized design with four replicates was conducted at the same college to evaluate the germination and viability parameters of plant seeds and radicle and plumule characteristics. Findings showed that wheat and barley seeds were more resistant to licorice root extract than either weed seed. As licorice root aqueous extract concentrations increased from 25 to 100%, the inhibitory effect of allelopathic materials for all germination parameters was increased. The interaction between treatments gave the number (0.00) for all parameters studied by the white mustard plant and 100% licorice root extract.

Keywords: Licorice, Allelopathy, Germination, Chlorophyll, Biological Yield.

1. Introduction

Allelopathy is a biological process of chemical interactions among plants, and this process has a lot of potential to be employed as a practical and sustainable method of controlling weeds in field crops^{1, 2}. Allelopathy is an ecologically significant biochemical phenomenon that involves any direct or indirect negative or positive impact that one plant (donor) has on another (target)

through the release of chemical compounds into the environment^{3, 4}. The complex phenomenon known as allelopathy involves both stimulatory and inhibitory effects on plant activity brought on by the release of specific chemical compounds known as allelochemicals. Allelopathy can also be used in field crops following agricultural rotation, cover crops, and plant extracts for organic pest control. Allelopathic plant extracts can be used to efficiently control insect pests and weeds⁵⁻⁷. Plants, owing to their high number of various bioactive compounds, represent the principal raw material for producing valuable and useful bioproducts (e.g., food, cosmetics, medicines, bio-stimulants, biopesticides, and feed). Various plant parts, for example, seeds, fruits, flowers, stems, leaves, and roots, can be used for their manufacture. Nowadays, there is a clear requirement to develop novel, effective, and environmentally friendly methods of stimulation of plant growth and crop protection. Plant-based extracts are new, natural, and multi-compound products that could be utilized for these purposes⁸. Weeds are among the most difficult problems confronting agricultural production worldwide. Weeds vie for light, nutrients, water, and space, which diminishes crop growth and yield. Furthermore, weeds also harbor insect pests and bacterial, fungal, and viral pathogens, additionally reducing the crop yield. As the global population is anticipated to surpass a billion by 2050, world food production cannot risk any substantial yield loss due to weed competition. One of the options to surmount these issues is strategies that use allelopathy and the implementation of bio-herbicides for weed control and sustainability of agriculture⁹.

Licorice is known to possess water-soluble compounds that are allelopathic to other plants, and the root of this species is the source of licorice commercially in pharmacopoeia. Reviews of allelopathy find the residues of various crops have a phytotoxic action on other plants¹⁰. However, the same researchers studied the effect of licorice leaf and root aqueous extracts at different concentrations on germination and seedling growth of three plant species: wheat, wild oat, and milk thistle. They are found with increasing the concentrations from 30 to 50%; the inhibitory impact of allelopathic materials on germination, growth, seed vigor index, and fresh and dry weight of seedlings significantly increased. A field experiment was conducted to study the effects of foliar application of different levels of licorice root extract on some growth characteristics and yield components of three wheat plant varieties. They found that significant differences in licorice concentration affect growth and yield parameters¹¹.

The aim of this study was designed to investigate the perception of plastic houses and a laboratory experiment concerning the effect of licorice root aqueous extracts on germination and seedling development of wheat, barley, cephalaria, and white mustard plants. It will also propose recommendations for effective allelochemical discovery of suitable herbicides for weed plants and fertilizer for field crops based on the research results.

2. Materials and Methods

2.1. Study Site

The first experiment was conducted in the plastic house from December 30th, 2024, to April 24th, 2025, at Grdarasha Research Field, College of Agricultural Engineering Sciences, Salahaddin University – Erbil, to study the effect of foliar application of licorice (*Glycyrrhiza glabra* L.) on chlorophyll content and yield of some crop and weed plants. This experiment was carried out using pots with a height of 10 cm, 12 cm in diameter for the upper base, and 9 cm for the lower base. The total number of pots is 60. Pots were filled with loam and peat moss. **Table 1** at the rate (2:1), five seeds per pot were sown at a depth of 3 cm on December 30th, 2024, in the plastic house by using a completely randomized design (CRD) with three replications. After germination, on January 10th, thin the plants to two plants per pot. Four species of plant were used in the experiment: wheat (*Triticum aestivum*), Adana variety; Barley (*Hordeum vulgare*), Aksad14 variety; Syrian cephalaria (*Cephalaria syriaca*); and wild white mustard (*Sinapis alba*). Moisture was maintained by adding water when needed.

Table 1. Some chemical and physical properties of the pot soil

Soil properties	Soil component	
Particle size distribution (g kg ⁻¹)	Sand	12.5
	Slit	42.5
	Clay	45
Texture Class	Silty Clay	
pH	7.42	
Electrical Conductivity (EC) ds m ⁻¹	0.2	
Organic Matter (%)	0.9	
Total Nitrogen (%)	0.18	
Available Phosphorus (ppm)	3.75	
Available Potassium (ppm)	100	

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2.2. Experiment factors

Licorice (*Glycyrrhiza glabra* L.) root was gathered from the Khabat region, which is located in the west of Erbil, Kurdistan region/Iraq, on December 1th, 2024. The samples were left for two weeks to be dried by air and then sent to Salahaddin University-Erbil's College of Agricultural Engineering Sciences Laboratory, where they were ground into fine particles using a grinder and prepared for testing. Aqueous licorice root extract was prepared by mixing 30 grams of licorice root powder and 200 milliliters of distilled water to create an aqueous extract and placed in a shaker machine to improve mixing. After that, the samples were placed in an oven at 35°C for 2 days. Next, filtering the extracts using filter paper and then adding distilled water in order to complete the volume to 300 ml. Finally, the extract was kept in a freezer at 4°C until needed. Gas Chromatography-Mass Spectrometry (GC/MS) was done for the aqueous licorice root extract sample in **Table 2** according to ^{12,13}.

Table 2. Analysis GC-MS of an extract of licorice root

Component Name	Retention Time	Peak Area%	Component Name	Retention Time	Peak Area%
Maltol	5.201	0.14	Pentadecanoic acid, 14-methyl-, methyl ester	10.64	0.42
4H-Pyran-4-one, 2,3-dihydro-3,5-dihydroxy-6-methyl-	5.44	0.19	n-Hexadecanoic acid	10.9	5.01
Berteroin	5.572	0.29	(2S,2'S)-2,2'-Bis[1,4,7,10-tetraoxacyclododecane]	11.2	0.36
1,7,7-Trimethylbicyclo[2.2.1]heptan-2-ol	5.653	0.19	2H-Pyran, 2-(2-heptadecynyloxy)tetrahydro-	11.459	0.19
Dodecane, 2-methyl-	5.719	0.15	Tridecanoic acid	11.586	0.11
Phthalan	5.939	0.22	9,12-Octadecadienoic acid (Z,Z)-	12.117	1.26
m-Guaiacol	5.976	0.15	Octadecanoic acid	12.297	1.16
5-Hydroxymethylfurfural	6.023	0.46	Heptasiloxane, hexadecamethyl-	12.499	0.34
D-Carvone	6.106	0.12	n-Nonadecanol-1	13.137	0.36
Nonanoic acid	6.153	0.12	Heptasiloxane, hexadecamethyl-	13.341	0.3
2-Cyclohexen-1-ol, 2,6,6-trimethyl-	6.218	0.27	Heptasiloxane, hexadecamethyl-	14.202	0.27
Silane, [(1,1-dimethyl-2-propenyl)oxy]dimethyl-	6.256	0.16	n-Tetracosanol-1	14.494	0.17
Hydroquinone	6.433	0.35	Glabridin	22.687	3.42
2-Methoxy-4-vinylphenol	6.522	1.23	Cyclononasiloxane, octadecamethyl-	15.193	0.22
Phenol, 2,6-dimethoxy-	6.732	0.22	Heptasiloxane, hexadecamethyl-	16.391	0.17
Phenol, 2-methoxy-3-(2-propenyl)-	6.769	0.32	Benzoic acid, 4-amino-3-(3,7,11,15,19,23,27,31-octamethyl-2,6,10,14,18,22,26,30-dotriacontaoctaenyl)-, (all-E)-	17.558	0.34

Component Name	Retention Time	Peak Area%	Component Name	Retention Time	Peak Area%
1,3:2,5-Dimethylene-l-rhamnitol	7.685	21.31	Parvisoflavone B	17.695	0.48
2,2'-Isopropylidenedifuran	7.754	6.45	6-Methoxy-17,17-dimethyl-3,12,18-trioxapentacyclo	18.051	0.62
Dodecanoic acid	7.987	1.48	N-(4-Bromophenyl)adamantan-2-amine	18.425	0.25
Phenol, 4-ethenyl-2,6-dimethoxy-	8.086	0.79	1,2-benzenedicarboxaldehyde, 4-(1,1-dimethylethyl)-	18.793	0.14
Benzenepropanoic acid, 4-hydroxy-, methyl ester	8.222	0.75	trioxapentacyclo	19.006	0.89
1,2,3,4-Tetra-O-acetyl-1-deuterio-5-O-methyl-D-ribitol	8.379	0.81	17-Methoxy-4-methyl-d-homo-18-norandrost-4,8,13,15,17-pentaen-3-one	19.413	0.31
Ethanone, 1-(2,4,5-triethylphenyl)-	8.524	1.03	Estra-1,3,5(10),8-tetraen-17-one, 3-methoxy-	19.746	0.25
Benzenepropanoic acid, 4-hydroxy-	8.643	6.73	Phenol, 4,4'-(1-methylethylidene)bis[2-(2-propenyl)-	20.037	0.78
3,4,4-Trimethyl-3-(3-oxo-but-1-enyl)-bicyclo [4.1.0]heptan-2-one	8.713	9.19	4'-O-Methylglabridin	21.02	2.73
3-O-Methyl-d-glucose	9.238	20.93	Cholesta-4,6-dien-3-ol, (3.beta.)-	22.053	0.39
6H-Chromeno[6,7-d]oxazol-6-one, 8-methyl-	9.736	0.92	Normorphine, N,O,O'-tris(trifluoroacetyl)-	22.353	0.12
Euparin	9.985	0.44	Campesterol	25.821	0.18
Pentadecanoic acid	10.154	0.48	Stigmasterol	26.574	0.54

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Different licorice root extracts diluted from the stock solution 100% to the required concentrations (0, 25, 50, 75, and 100%) were used by foliar application. A surfactant agent, Tween 40, was added at a concentration of 0.1% to the solutions. Spraying was carried out at two stages; the first spray was applied two months from the sowing date (as the plant growth was ready for spraying), and the second spray was applied two days from the first spray. The spray was carried out early in the morning till run-off.

2.3. Studied parameters

Two plants were selected from each pot to study the biological yield (gm), inhibition, response ratio of biological yield %¹⁴ and chlorophyll content. Chlorophyll content was measured three times in (1/3, 6/3, 10/3 – 2025) with five-day intervals between them; the "Chlorophyll Meter SPAD-502 Plus" was used for total chlorophyll estimation¹⁵. (Equation 1 and 2)

$$\text{Inhibition ratio of biological yield\%} = \frac{\text{yield control} - \text{yield treated}}{\text{yield control}} \times 100 \quad (1)$$

$$\text{Response ratio of biological yield\%} = \frac{\text{yield treated} - \text{yield control}}{\text{yield treated}} \times 100 \quad (2)$$

The second experiment was carried out at the College of Agricultural Engineering Sciences laboratory to investigate the efficiency of licorice root extract on the germination and viability parameters of plant seeds. 25 seeds of each plant species were placed in separate petri dishes lined with filter paper, each having a diameter of 9 cm. Since these were the treatment petri plates, 10 milliliters of licorice root extract were added to the petri dishes. For the control group, petri dishes received only 10 milliliters of distilled water. Each seed species had four replications, including test and control treatments. In a growth chamber, petri dishes were incubated at 22°C. Every day, the percentage of seed germination%, germination speed (seed.day⁻¹)¹⁶, radicle and plumule lengths (cm), radicle dry weight, plumule dry weight (g), radicle and plumule elongation velocity (cm.day⁻¹)¹⁴, peak value (%day)¹⁷, mean daily germination (% day)¹⁸, germination value¹⁹ and seedling vigor index (cm/100)²⁰ of the sprouted seedlings were recorded as detailed below (Equations 3-19):

$$\text{Germination percentage \%} = \frac{\text{Number of germinated seed}}{\text{Total number of seeds sown}} \times 100 \quad (3)$$

$$\text{Germination speed (seed.day}^{-1}\text{)} = \sum \frac{\text{number of germinated seeds}}{\text{number of days}} \quad (4)$$

$$\text{Radicle or plumule elongation velocity (cm.day}^{-1}\text{)} = \sum \frac{\text{Radical or plumule length}}{\text{Total number of days}} \times 100 \quad (5)$$

$$\text{Peak value (\%day)} = \frac{\text{Final germination percentage}}{\text{Number of days to reach maximum germination}} \quad (6)$$

$$\text{Mean daily germination (\% day)} = \frac{\text{Final germination \%}}{\text{Total number of days in test}} \quad (7)$$

$$\text{Germination value} = \text{mean daily germination \%} \times \text{peak value} \quad (8)$$

$$\text{Seedling Vigor Index (cm/\%)} = \text{Germination percentage} \times \text{seedling length} \quad (9)$$

2.4. Statistical analysis and experimental design

The experiments were designed according to a factorial completely randomized design (CRD) with three replicates for the pot experiment and four replicates for the laboratory experiment. Comparisons between means were made using Duncan's Multiple Range Test at 5% for morphological characteristics (**Table 1**). However, 1% was used for laboratory characteristics. The statistical analysis was carried out using the SPSS (Statistical Package for Social Sciences) program, version 22.0, in 2019²¹.

3. Results

3.1. Plastic house parameters

Table 3 clarifies the effect of plant species, licorice foliar application, and their interaction on chlorophyll content and biological yield. Findings show no significant effect between plant species for the chlorophyll in the first measure was found, while for other chlorophyll measurements, white mustard recorded the highest values (44.85 and 41.87 SPAD) among plant species. The wheat plant significantly increased the biological yield to 0.71 g as compared with other plants, and the minimum rate (0.29 g) was obtained by the Cephalaria plant. Biological yield was stimulated to 3.57% in the Cephalaria plant, and this response decreased in white mustard to -41.66%; vice versa, with the inhibition ratio, biological yield was inhibited by 41.66% in white mustard, whereas the inhibition ratio significantly declined to -3.57% in the Cephalaria plant. No significant differences in licorice root extract spray were observed for chlorophyll content. While the biological yield production increased to 0.47 g at 25% licorice extract and the minimum value (0.31) at 75%. Licorice root extract foliar application significantly responded at 100% and recorded the highest amount (3.50%), while the lowest ratio (-29.50%) was at the 50% licorice level for the response ratio of biological yield. In contrast, it inhibited the production of biological yield and registered a maximum value (29.50%) with 50% and a minimum ratio (-3.50) with 100%. The same table elucidated the significant ($P \leq 0.05$) impact of combination effects between plant species and licorice foliar application root extract on chlorophyll content that was measured at different time intervals. The highest values (37.30, 53.61, and 47.03 SPAD), respectively, for the three chlorophyll-measured periods were reported for white mustard with increasing licorice concentration. While the smallest amount (21.16, 23.70, and 2.35 SPAD, respectively) was found with barley at 100% licorice level, followed by wheat at 50% and Cephalaria at 25%. Biological yield significantly increased with the decreased concentration of licorice and recorded the maximum rate (0.91 g) with the wheat plant at 25%. But the minimum values (0.05 g) were obtained with plant weeds, especially white mustard at 50%. In this study, the root extract of a licorice plant stimulated and inhibited the growth of plant species by different degrees. The ratio of crops responded more than the weeds did. In contrast to the inhibition ratio, the most sensitive plants were weeds, followed by crops, because white mustard recorded the maximum value (64.58%) of inhibition ratio in biological yield at 50%.

Table 3. Influence of plant species, licorice root extract foliar application, and their interaction on chlorophyll content and biological yield

Plant species	Chlorophyll FC (SPAD)	Chlorophyll SC (SPAD)	Chlorophyll TC (SPAD)	Biological yield (g)	Response ratio of biological yield %	Inhibition ratio of biological yield %
Wheat	29.16 a	28.97 b	31.86 b	0.71 a	-15.32 a	15.32 b
Barley	28.41 a	29.66 b	31.13 b	0.55 b	-2.42 a	2.42 b
Cephalaria	31.61 a	29.22 b	31.95 b	0.29 c	3.57 a	-3.57 b
White Mustard	32.46 a	44.85 a	41.87 a	0.11 d	-41.66 b	41.66 a
Licorice extract concentration (%)	Chlorophyll FC (SPAD)	Chlorophyll SC (SPAD)	Chlorophyll TC (SPAD)	Biological yield (g)	Response ratio of biological yield %	Inhibition ratio of biological yield %
0	30.75 a	30.04 a	34.06 a	0.45 ab	-----	-----
25	30.88 a	33.75 a	34.30 a	0.47 a	-2.81 a	2.81 b
50	29.54 a	32.97 a	35.36 a	0.31 c	-29.50 b	29.50 a
75	32.43 a	33.89 a	33.24 a	0.36 bc	-27.04 b	27.04 a
100	28.44 a	35.21 a	34.03 a	0.44 ab	3.50 a	-3.50 b
Plant species × Licorice extract concentration	Chlorophyll FC (SPAD)	Chlorophyll SC (SPAD)	Chlorophyll TC (SPAD)	Biological yield (g)	Response ratio of biological yield %	Inhibition ratio of biological yield %
Wheat 0%	31.56 abc	30.10 d	32.70 b-f	0.80 ab	-----	-----
Wheat 25%	32.60 abc	34.56 cd	33.78 b-f	0.91 a	13.16 bc	-13.16 de
Wheat 50%	23.53 bc	23.70 d	29.10 ef	0.45 de	-43.62 def	43.63 abc
Wheat 75%	29.26 abc	31.96 d	32.68 b-f	0.68bc	-15.22 b-f	15.22 a-e
Wheat 100%	28.83 abc	24.51 d	31.03 c-f	0.68 bc	-15.63 b-f	15.63 a-e
Barley 0%	27.91 abc	25.20 d	31.03 c-f	0.55 cd	-----	-----
Barley 25%	32.26 abc	30.20 d	37.48 a-e	0.63 bcd	15.75 b	-15.75 e
Barley 50%	28.10 abc	29.98 d	30.65 c-f	0.46 de	-15.75 b-f	15.75 a-e
Barley 75%	32.60 abc	25.63 d	30.08 def	0.52 cd	-4.84 b-e	4.84 b-e
Barley 100%	21.16 c	37.28 bcd	26.41f	0.52 cd	-4.84 b-e	4.84 b-e
Cephalaria0%	33.20 abc	31.40 d	30.05 def	0.28 ef	-----	-----
Cephalaria 25%	25.66 abc	31.83 d	25.35 f	0.22 fg	-21.42 b-f	21.42 a-e
Cephalaria 50%	31.23 abc	28.35 d	42.40 ab	0.29 ef	5.95 bcd	-5.95 cde
Cephalaria 75%	35.06 ab	24.35 d	30.30 def	0.17 fg	-38.09 c-f	38.09 a-d
Cephalaria 100%	32.90 abc	30.16 d	31.65 c-f	0.47 de	67.85 a	-67.85 f
White Mustard 0%	30.33 abc	33.46 d	42.48 ab	0.16 fg	-----	-----
White Mustard25%	33.00 abc	38.43 bcd	40.60 abc	0.13 fg	-18.75 b-f	18.75 a-e
White Mustard50%	30.80 abc	53.61 a	39.31 a-d	0.05 g	-64.58 f	64.58 a
White Mustard75%	37.30 a	49.86 ab	39.91 a-d	0.08 g	-50.00 ef	50.00 ab
White Mustard100%	30.86 abc	48.88 abc	47.03 a	0.10 fg	-33.33 b-f	33.33 a-e

*The similar letters between treatments means there are no significant differences between them using Duncan's Multiple Test at 5% level.

3.2. Germination parameters

According to the results presented in **Table 4**, findings show that significant variation was recorded for all germination characteristics between plant species with application of licorice root extract. The wheat plant occupies the first position among all plant species to give the highest rates for all germination parameters, and the barley plant occupies the last position, excepting germination speed character, which was recorded the minimum value (3.38 seed.day⁻¹) for white mustard. With increasing the concentration of licorice root extract, germination

parameters significantly decrease. Simultaneously, the inhibition of germination increases with the increase of concentrations to 100%.

Table 4. Influence of plant species, licorice root extract application, and their interaction on some germination characteristics

Plant species	Germination percentage %	Germination Speed (seed.day ⁻¹)	Peak Value (% day)	Mean Daily Germination (% day)	Germination Value
Wheat	77.06 a	20.75 a	11.58 a	9.63 a	116.09 a
Barley	14.93 c	3.62 c	2.44 b	1.86 c	7.90 b
Cephalaria	68.00 a	16.48 b	10.26 a	8.50 a	92.37 a
White Mustard	28.26 b	3.38 c	3.53 b	3.53 b	19.83 b
Licorice extract concentration (%)	Germination percentage %	Germination Speed (seed.day ⁻¹)	Peak Value (% day)	Mean Daily Germination (% day)	Germination Value
0	68.66 a	16.76 a	9.56 a	8.58 a	93.12 a
25	52.33 b	13.11 b	10.07 a	6.54 b	83.17 a
50	41.00 bc	9.68 c	5.16 b	5.12 bc	45.91 b
75	44.00 b	8.65 c	5.72 b	5.50 b	44.99 b
100	29.33 c	7.10 c	3.80 b	3.66 c	28.06 b
Plant species × Licorice extract concentration	Germination percentage %	Germination Speed (seed.day ⁻¹)	Peak Value (% day)	Mean Daily Germination (% day)	Germination Value
Wheat 0%	96.00 a	25.85 a	13.62 abc	12.00 a	165.18 a
Wheat 25%	77.33 ab	22.22 ab	16.76 a	9.66 ab	160.88 ab
Wheat 50%	73.33 bc	17.92 bc	10.19 a-e	9.16 ab	100.09 a-e
Wheat 75%	68.00 abcd	19.14 abc	8.50 b-h	8.50 a-d	72.91 c-g
Wheat 100%	70.66 abc	18.61 bc	8.83 b-g	8.83 abc	81.41b-g
Barley 0%	40.00 ef	9.42 de	5.00 d-i	5.00 ef	27.16 efg
Barley 25%	20.00 fg	4.74 ef	3.02 e-i	2.50 fg	8.31 fg
Barley 50%	5.33 g	1.42 f	1.60 ghi	0.66 g	1.24 g
Barley 75%	6.66 g	1.71 f	1.71 fgghi	0.83 g	2.38 g
Barley 100%	2.66 g	0.81 f	0.88 i	0.33 g	0.44 g
Cephalaria0%	82.66 ab	22.45 ab	12.61 a-d	10.33 ab	130.63 a-d
Cephalaria 25%	70.66 abc	20.42 ab	15.35 ab	8.83 abc	134.42 abc
Cephalaria 50%	66.66 b-e	17.86 bc	8.33 b-h	8.33 b-e	73.50 c-g
Cephalaria 75%	76.00 ab	12.69 cd	9.50 a-f	9.50 ab	92.91 a-f
Cephalaria 100%	44.00 c-f	8.99 de	5.50 d-i	5.50 c-f	30.41 efg
White Mustard 0%	56.00 b-e	9.31 de	7.00 c-i	7.00 b-e	49.50 d-g
White Mustard25%	41.33 def	5.07 ef	5.16 d-i	5.16 def	29.08 efg
White Mustard50%	18.66 fg	1.51 f	2.33 fgghi	2.33 fg	8.83 fg
White Mustard75%	25.33 fg	1.04 f	3.16 e-i	3.16 fg	11.75 fg
White Mustard100%	0.00 g	00.0 f	0.00 i	0.00 g	0.00 g

*The similar letters between treatments means there are no significant differences between them using Duncan's Multiple Test at 1% level.

Also, the interaction between plant species and licorice root extract aqueous solution significantly affected germination characteristics. In general, the germination parameters' inhibition of weed seeds increased with more licorice root extract. The maximum values (96.00%, 25.85 days, 16.76%, 12.00%, and 165.18, respectively) were recorded by the wheat plant with control treatment, while the minimum (0.00) for all germination parameters by the white mustard plant was at 100% licorice application

3.3. Plumule and radicle parameters

As shown in **Table 5** radicle, plumule, and seedling parameters were significantly affected by aqueous extracts of licorice. Results showed that radicle dry weight and radicle elongation velocity significantly increased to 7.86 mg and 21.78 cm/day⁻¹ in barley plants, whereas plumule dry weight, plumule elongation velocity, and seedling vigor index had a greater value (4.22 mg, 14.86 cm/day⁻¹, and 908.01, respectively) in wheat plants.

Table 5. Influence of plant species, licorice root extract application, and their interaction on some radicle and plumule characteristics

Plant species	Radicle dry weight (mg)	Radicle elongation velocity (cm.day ⁻¹)	Plumule dry weight (mg)	Plumule elongation velocity (cm.day ⁻¹)	Seedling vigor index
Wheat	6.86 a	13.25 b	4.22 a	14.86 a	908.01 a
Barley	7.86 a	21.78 a	3.39 a	10.16 b	237.33 b
Cephalaria	1.37 b	9.26 bc	0.55 b	4.04 c	129.93 b
White Mustard	5.30 a	4.94 c	0.82 b	7.82 b	213.45 b
Licorice extract concentration (%)	Radicle dry weight (mg)	Radicle elongation velocity (cm.day ⁻¹)	Plumule dry weight (mg)	Plumule elongation velocity (cm.day ⁻¹)	Seedling vigor index
0	7.21 a	21.48 a	5.39 a	26.27 a	832.09 a
25	4.92 a	16.03 b	1.74 b	9.05 b	325.07 b
50	6.33 a	10.88 bc	1.77 b	5.29 bc	267.23 b
75	4.59 a	8.24 cd	1.39 b	3.54 c	215.01 b
100	3.69 a	4.90 d	0.94 b	1.94 c	191.51 b
Plant species × Licorice extract concentration	Radicle dry weight (mg)	Radicle elongation velocity (cm.day ⁻¹)	Plumule dry weight (mg)	Plumule elongation velocity (cm.day ⁻¹)	Seedling vigor index
Wheat 0%	10.48 a	24.68 abc	9.56 a	38.25 a	1933.70 a
Wheat 25%	6.00 abc	14.54 c-f	3.05 bc	11.79 cd	679.02 bc
Wheat 50%	8.00 abc	11.13 d-g	4.03 b	10.41 cde	836.86 b
Wheat 75%	3.90 abc	8.62 efg	2.41 bc	7.77 c-f	451.80 b-e
Wheat 100%	5.95 abc	7.26 efg	2.03 bc	6.06 c-f	638.66 bcd
Barley 0%	11.48 a	34.59 a	9.62 a	30.92 a	203.68 cde
Barley 25%	6.02 abc	28.38 ab	2.66 bc	8.63 c-f	679.02bc
Barley 50%	9.05 ab	21.84 bcd	2.03 bc	5.11 c-f	66.93 de
Barley 75%	6.20 abc	15.61 cde	1.98 bc	4.40 c-f	66.00 de
Barley 100%	6.56 abc	8.50 efg	0.66 bc	1.71 ef	28.93 e
Cephalaria0%	1.38 bc	12.18 d-g	0.91 bc	13.38 c	191.73 cde
Cephalaria 25%	0.97 c	13.11 c-f	0.32 c	2.92 def	132.60 cde
Cephalaria 50%	1.63 bc	8.39 efg	0.38 c	2.09 ef	92.50 de
Cephalaria 75%	1.35 bc	8.74 efg	0.45 c	1.81 ef	134.40 cde
Cephalaria 100%	1.54 bc	3.86 efg	0.70 bc	0.00 f	98.45 de
White Mustard 0%	5.50 abc	14.46 c-f	1.46 bc	22.53 b	381.80 b-e
White Mustard25%	6.70 abc	8.100 efg	0.93 bc	12.86 c	325.06 b-e
White Mustard50%	6.66 abc	2.17 fg	0.65 bc	3.54 def	152.53 cde
White Mustard75%	6.93 abc	0.00 g	0.71 bc	0.16 f	207.86 cde
WhiteMustard100%	0.71 c	0.00 g	0.37 c	0.00 f	0.00 e

*The similar letters between treatments mean there are no significant differences between them using Duncan's Multiple Test at 1% level.

As well as, these parameters significantly declined for weed plants. With application of licorice root extract, these parameters significantly decreased with an increased level of treatment. In the same table showing the interaction between treatments, parameters significantly recorded the highest values (10.48 mg, 34.59 cm/day, 9.56 mg, 38.25 cm day⁻¹ and 1933.70) for wheat and barley plants without adding any licorice extract aqueous, whereas the lowest rates ranged from 0.00 to 0.71 and were obtained with weed plants at 75 and 100% licorice concentration.

4. Discussion

The results in **Table 1** show significant differences between plant species of chlorophyll estimate, biological yield, response, and inhibition rate of biological yield. The variation between varieties may be related to the difference in genetic formation between varieties²². Licorice root aqueous extract spray had a significant effect on these parameters. Also, for interaction between species, licorice extract foliar application showed that a weed plant with a high concentration was superior. Furthermore, the chemical composition of the licorice root extract plant components under investigation was examined using GC-MS and mass spectrometry. A total of 58 substances were shown in **Table 2**, it was noted that several compounds showed up in large quantities, such as the compounds 1,3:2,5-Dimethylene-l-rhamnitol (21.31%) and 3-O-Methyl-d-glucose (20.93%). However, a few additional chemicals, like maltol (0.14%) and nonanoic acid (0.12%), were present at extremely small levels. According to previous research, phenolic chemicals dramatically reduce plant weed development^{23, 24}. Licorice extract contains iron, magnesium, and nitrogen, which are essential elements in the composition of the chlorophyll molecule, which is important in the process of photosynthesis and influences the growth and development of plant^{25, 26, 27}.

From the findings in **Table 4** wheat plant occupies the first position among all species in germination characteristics and the barley plant in the last position. Licorice root extract spray inhibited the germination parameters and control recorded the greater values. With interaction between treatments, wheat with control selected the greater number and white mustard at 100% decline to 0.00 for all germination parameters. In this context, it is observed that the main reason inhibiting the germination of weed seeds could be the toxicity effects of licorice allelochemicals, including phenolic compounds² licorice root extract contains a high concentration of phenolic and flavonoid compounds, which may explain its significance **Table 2**. The decrease in weed seed germination here is due to the inhibitory effect of licorice extract, which contains substances such as phenols, tannins, and coumarin compounds, which are toxic at high concentrations. In addition, licorice contains chemical compounds that are soluble in water, and therefore increasing the concentration of the aqueous extract, whether through the process of seeds being soaked in water, means an increase in the amount of these compounds, which vary in their effect on cell division and elongation, and some compounds may affect the activity of some enzymes that contribute to this process, such as amylase-Q^{28, 29, 30}.

The results presented in **Table 5** show that wheat and barley plants produced higher data for radicle, plumule, and seedling vigor index parameters, and these parameters were inhibited with spraying at 100%. In addition, in interaction between treatments, radicle, plumule, and seedling vigor index parameters of weed plants are inhibited with 75% and 100% licorice extracts. The results confirm that increasing the concentration of licorice extract with direct addition treatments to the plates reduces the root length. The reason for this is that the licorice extract contains tannins that are highly toxic when used in high concentrations, and this inhibits the length of the root system, as they bind to enzymes and reduce their effectiveness. They may bind to enzymes specific to the intermediate reactions leading to the formation of an auxin, which leads to obstructing its formation or forming it in very small quantities³¹. High concentrations hinder the absorption of nutrients, which in turn reduces vital activities and reduces growth. At lower concentrations, the hindrance is less due to the low osmotic pressure in the extract, which allows the absorption of water and nutrients³². Licorice root extract dramatically decreased the plumule, radicle, and seedling vigor index due to their high phenolic acid content **Table 2**, which inhibits photosynthesis, respiration, and root and stem growth rate; it reduced the seedling length relative to the control. Previous research has documented the reaction of early growth and germinating seeds to phenolic compounds, demonstrating that these chemicals support the plant growth system and may influence plant hormones to influence seedling growth^{27, 33}.

5. Conclusions

According to the findings of this study, licorice root aqueous extracts frequently inhibit the growth and germination of the weed plants under investigation. Because the licorice aqueous extract at 50 and 75% concentrations gives the highest values in weed control efficiency in this study. However, chlorophyll content had a significant effect on white mustard at 50, 75, and 100% licorice root extract. Additionally, the germination percentage of the plant species was considerably decreased to 0% by 100% licorice root extract treatment. Allelopathic potentiality may be increased by the presence of allelochemical substances. Bioherbicides could be a new weed control strategy and an extra tool for plant development because they are more ecologically friendly than chemical herbicides.

Conflict of Interest

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

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