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ORIGINAL ARTICLE

An allelopathic evaluation of aqueous *Aloe vera* leaf and root extracts on the weed *Sonchus oleraceus* associated *Vicia faba* L.

Kowthar Gad El-Rokiek[1]*, Abeer Nasr Shehata[2], Samia Ameen Saad El-Din[1], Shahira Ali Tarraf[1]

[1] Botany Department, National Research Centre, Giza, Egypt

[2] Department of Biochemistry, National Research Centre, Giza, Egypt

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*Corresponding address:
kowtharelrokiek@gmail.com

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Abstract

This study aimed to evaluate the bioherbicidal effect of aqueous fresh extracts of leaves and roots of the *Aloe vera* plant on the broad leaf weed growth of *Sonchus oleraceus* associated faba bean plants. During the winters of 2020/2021 and 2021/2022, two pot experiments were carried out in the greenhouse of the National Research Center. Leaf and root aqueous extracts of *Aloe vera* were applied as soil and/or spray treatments at different concentrations. The results showed that there was significant inhibition in the fresh and dry biomass of *S. oleraceus* and was maximum with application of soil treatment (10%) of the leaf extract sequenced by spraying leaf extract at 20%. Furthermore, the inhibition of the weed growth was accompanied by an increase in the growth and yield of faba bean. The results indicated that phenols, flavonoids, alkaloids, tannins and saponins were present in the leaf extract, and there were smaller amounts of tannins and saponins in the root extract than in the leaf extract. Total phenols, flavonoids, alkaloids in the leaf extract was more than three times that of the root extract. The results also revealed that the presence of higher concentrations of natural substances in the leaf extract than in the root extracts gave it its efficiency in inhibiting the growth of *S. oleraceus* weeds.

Keywords: alkaloids, bioactive materials, broad leaf weed, faba bean, water extract

Introduction

A significant legume in Egypt is the faba bean (*Vicia faba* L.). Due to the fact that it boosts farmers' revenue, it has evolved into a strategic crop. It is beneficial for human nutrition, animal feed, and industrial purposes in addition to being an excellent source of vegetarian protein (Kandil 2022). To fulfill the demands of the expanding Egyptian population, whose diet mainly consists of faba beans, the major objectives are to increase faba bean productivity and improve crop quality and weed management is necessary to produce faba beans profitably (Abdellatif *et al*. 2023).

Weed interference is a serious problem in crop plants due to competition with water, light and nutrient uptake (El-Metwally and El-Rokiek 2019). Potentially *Sonchus oleraceus* **c**an negatively affect agriculture through crop competition (Cardenas *et al*. 2022). It can also cause significant financial losses, which must be avoided by good weed management planning, in which chemical, cultural, and biological control stand out (Abdellatif *et al*. 2023).

The overuse of herbicides has caused many problems such as environmental pollution, and unsafe yield crop production due to residual effects of herbicides. In addition, resistance of weeds to herbicides due continuous use has developed (Mehdizadeh and Abadan 2018). So, scientists must solve these problems by searching for alternative methods of weed control that would result in a safe environment, safe crops and consequently safe human health. One of these methods is allelopathy.

Allelopathy plays an important role in the evolution of plant communities by production of potential natural allelochemicals (Roby *et al*. 2013). Many plant species are able to produce and release bioactive secondary metabolites into the environment (Li *et al*. 2022). These secondary metabolites released into the soil reduce the growth of other plants (Bendjedid *et al*. 2022). Allelochemicals are present in the stems, leaves, roots, flowers, fruits and seeds of some plants (El-Rokiek *et al*. 2022a).

The genus Aloe contains more than 360 species. *Aloe vera* is an important medicinal plant related to the Liliaceae family. It is a succulent herb which grows in many countries (Mahor and Ali 2016). *Aloe vera* **e**xcretions have been used for several medical and cosmetic applications since ancient times (Tanaka *et al*. 2006). The gel of *A. vera* has different biological and physiological activities. Its leaf parenchymatic cells contain liquid yellow latex and clear gel (Ni *et al.* 2004). *Aloe vera* latex is rich in essential amino acids, mono- and polysaccharides, lignin, macronutrients, micronutrients, vitamins, gibberellins and salicylic acid (Boudreau and Beland 2006). In general, medicinal plants contain large numbers of secondary metabolites (Li *et al*. 2022**)**.

Murakami *et al*. (2009) reported that *A. arborescen*s Miller leaf extract showed phytotoxic activity on lettuce seed germination, growth of the hipocotyl-root axis and morphology alterations. The dry leaf and flower ethanolic extracts of *A. vera* at 0, 2.5, 5 and 10% resulted in no germination as well as no seedling growth of cereal rye (*Secale cereale*), garden cress (*Lepidium sativum*), redroot amaranth (*Amaranthus retroflexus*) and dandelion (*Taraxicum officinalis*) as was reported by Alipoor *et al*. (2012). Ilbas *et al*. (2012) recorded a reduction in the mitotic index of *Allium cepa* and root growth rate by *A. vera* gel extract. The water root extract of *A. ferox* reduced the germination of the tomato seeds, root and shoot lengths of the tomato seedlings with the percentage of inhibition increased as the concentration of the extract increased (Arowosegbe *et al.* 2012). Application of *A. vera* leaf water extracts at 10% reduced germination of black nightshade (*Solanum nigrum* L. emend Miller) by 19.6%. Extracts from fresh leaves of *A. vera* at different concentrations (2, 4, 6, 8, and 10%) reduced germination of barley and lettuce seeds, root length as well as seedling dry weight (Baličević *et al*. 2018). Moreover, Bendjedid *et al*. (2022) reported that aqueous leaf extract of *A. vera* at 10 and 25% caused complete inhibition in *A. hybridus* germination and inhibited its root length at all concentrations used (1, 5, 10 and 25%).

It is known that using allelopathy in controlling weeds as an alternative to chemical herbicides does not attain 100% control as do herbicides. So, in the current study aqueous extracts of both roots and leaves of *A. vera* were applied by spraying, in soils or both to reach an optimum natural method for controlling *S. oleraceus* associated faba bean plants.

Materials and Methods

Allelopathic material

Aloe vera seedlings were planted in pots for 1 month. Then they are pulled up. Leaves and roots were separated and used fresh, washed with tap water, then with distilled water for further cleaning, cut into very fine particles (1000 g each), then transferred to labelled beakers to which 5 l of distilled water was added. The soaking process continued for 48 hours. The produced extracts were collected and filtered through very fine mesh and pressed carefully for full extraction. This process was repeated according to the quantity of the extract needed. The extracts, made with fresh leaves and roots, were used at concentrations of 10 and 20%.

Pot experiment

Pot experiments were designed in the greenhouse of the National Research Centre, Egypt during two winter seasons 2020/2021 and 2021/2022. Faba bean seeds cv. Giza 3 were obtained from the Agricultural Research Centre, Egypt. The diameter of pots that were used in the study was 30 cm and the height was 30 cm also. The pots were filled with equal amounts of sieved soil (2 : 1 v/v clay and sand). Faba bean seeds that were the same size and color were selected. Seeds were cultivated 2 cm deep (five seeds in each pot) and allowed to germinate. All pots (except the weed free treatment) were infested with the same number of weeds (5 seeds) of *S. oleraceus* and mixed thoroughly at a depth of 2 cm in the soil. The seeds of faba bean and weed were sown at the same time. Thinning of faba bean seedlings was done 2 weeks after sowing so that three homogeneous seedlings were left per pot. Super phosphate was added to each pot before sowing while ammonium nitrate was added during plant growth. (2 : 1 w/w). The experiment consisted of 12 treatments.

The leaf and root water extracts of *A. vera* were applied in soil at 10%, while spray treatments were applied at 10 and 20% as follows:

1. Leaf extract (soil treatment + spray) at 10 + 10%.
2. Leaf extract (soil treatment + spray) at 10 + 20%.
3. Root extract (soil treatment + spray) at 10 + 10%.
4. Root extract (soil treatment + spray) at 10 + 20%.
5. Leaf extract (soil treatment) at 10%.
6. Root extract (soil treatment) at 10%.
7. Leaf extract (spray) at 10%.

8. Leaf extract (spray) at 20%.
9. Root extract (spray) at 10%.
10. Root extract (spray) at 20%.
11. Unweeded treatment.
12. Weed free plants.

The soil treatments were applied as 500 ml · pot^{-1} for both leaf and root extracts. The spray treatments were applied as 50 ml · pot^{-1}. The soil treatments were applied one time, while spray treatments were applied two times at two successive weeks starting from 3-week old plants.

Each treatment was represented by 6 pots. The pots were distributed with a complete randomized design. The data were taken at 45 days after sowing and at harvest.

Characters studied

Weeds

Three replicates were collected from each treatment 45 days after sowing (DAS) and at the end of the season. Fresh and dry biomass of *S. oleraceus* (g · pot^{-1}) were taken 45 DAS. The dry biomass of the weed was also taken at faba bean harvest.

Faba bean plants

Plant growth

In both seasons, the three faba bean plants in each pot for all treatments were collected to determine plant height (cm), number of leaves · plant^{-1}, fresh and dry biomass · plant^{-1} (g) at 45 DAS.

Yield and yield components

At harvest, the other three faba bean plants in each pot for all treatments were taken to determine number of pods/plants, number of seed · pods^{-1}, weight of seeds · plant^{-1}, and weight of 100 seeds (g).

Phytochemical screening of leaf and root extracts of *Aloe vera*

Extract preparation

Fresh leaves and roots of *A. vera* were collected and washed several times with tap water. Both materials were cut into small pieces, dried at 70°C for 48 h, and pulverized with a grinder. Ten grams of the above materials were soaked in 200 ml of distilled water and shaken in an orbital shaker at room temperature (23–25°C) for 24 hours to extract. Filter extracts from leaf and root samples were made using a Buchner funnel and Whatman #1 filter paper. The filtrate was snap-frozen at –55°C and dried with a lyophilizer for 48 hours to obtain leaf and root extract samples.

Determination of total phenolic compounds content

The modified Folin-Ciocalteu technique was used to determine the total phenolic compounds (Kaur and Kapoor 2002). The concentration was represented as mg of gallic acid equivalent per g of dry weight.

Determination of total flavonoid content

Total flavonoid content was measured using a modified colorimetric method (Chang *et al.* 2002). The total flavonoid content was expressed in milligrams of rutin equivalent per gram of dry weight.

Tannin determination

Tannins were estimated using the AOAC (1990) method. Calculation of tannin content was expressed in milligrams of tannin equivalent per gram of dry weight.

Determination of alkaloids

The Harborne method was used in 2005 for the quantitative assessment of alkaloids (Harborne 2005).

Determination of saponins

The saponin content of root and leaf extracts was deterimined using the method of Obadoni and Ochuko (2001).

Antioxidant properties

The reducing capacity of *Aloe vera* extract was calculated by measuring the antioxidant activity using 1,1-diphenyl-2-trinitrophenylhydrazine assay. The antioxidant activity of the extracts was tested as previously described with some modifications (Villano *et al.* 2007). Ascorbic acid was used as a positive control. The ability of the samples to scavenge DPPH free radicals was determined as follows:

$$\text{DPPH scavenging effect} = \frac{\text{Control OD (optical density)} - \text{Sample OD}}{\text{Control OD}} \times 100.$$

Statistical analysis

The data obtained were statistically analyzed according to Snedecor and Cochran (1991) and the means of treatments were compared by the least significant difference at 5% level of probability.

Results

Weeds

The results in Table 1 show significant inhibition in both fresh and dry biomass of the weed *S. oleraceus* by application of different concentrations of the leaf and

Table 1. Effect of natural extracts of leaves and roots of *Aloe vera* in controlling *Sonchus oleraceus* associated faba bean (Mean of the two seasons)

Treatments		Concentration [%]	Fresh biomass · pot^{-1}	Dry biomass · pot^{-1}	At the end of the season
Leaf extract	soil treatment + spray	10 + 10	9.595	2.070	8.876
		10 + 20	8.240	1.580	6.783
Root extract	soil treatment + spray	10 + 10	22.150	4.015	10.682
		10 + 20	15.450	2.470	9.003
Leaf extract	soil treatment	10	15.850	2.475	21.600
Root extract	soil treatment	10	18.075	2.960	23.566
Leaf extract	spray treatment	10	22.98	3.190	28.300
		20	16.955	2.533	25.133
Root extract	spray treatment	10	29.65	4.430	45.146
		20	21.215	3.073	34.400
Unweeded faba bean plants		0	36.385	6.805	49.500
Weed-free faba bean plants		0	0.000	0.000	0.000
LSD at 5%			1.042	0.673	1.590

root extracts of *A. vera* 45 days after treatments in comparison to unweeded control. The degree of inhibition differed with the type and method of application. The leaf extract induced higher significant reduction than root extract. The response of the weed to these treatments at harvest followed a similar trend. The most significant reduction was recorded by soil treatment (10%) of the leaf extract sequenced by spraying leaf extract at 20% at 45 DAS. The inhibition in dry weight reached 76.78% of the unweeded control. The results at harvest showed a similar trend. The corresponding results at the end of the season recorded 86.29% inhibition as compared to the unweeded control.

Faba bean

Vegetative growth

Table 2 shows significant increases over unweeded control in faba bean plant height, number of leaves/plant as well as fresh and dry weight · plant^{-1} with all treatments of leaf and root extract of *A. vera*, soil and/or spray. Incorporation of the leaf extract of *A. vera* in the soil at 10% followed by spraying 20% of the same extract revealed maximum results in the different growth characters as compared to their corresponding unweeded controls.

Table 2. Effects of natural extracts of leaves and roots of *Aloe vera* on different growth parameters of faba bean (Mean of the two seasons)

Treatments		Concentration [%]	Plant height [cm]	No. leaves · plant^{-1}	Fresh biomass · plant^{-1}	Dry biomass · plant^{-1}
Leaf extract	soil treatment + spray	10 + 10	53.33	10.33	14.73	2.656
		10 + 20	55.66	11.00	15.68	3.108
Root extract	soil treatment + spray	10 + 10	50.66	9.83	13.93	2.371
		10 + 20	52.66	10.00	14.61	2.308
Leaf extract	soil treatment	10	45.66	9.66	13.73	2.550
Root extract	soil treatment	10	44.33	9.33	13.21	2.263
Leaf extract	spray treatment	10	39.66	8.66	11.20	1.976
		20	43.33	9.00	11.68	2.053
Root extract	spray treatment	10	39.00	8.66	9.06	1.796
		20	42.66	8.83	10.85	1.901
Unweeded faba bean plants		0	35.00	8.00	8.02	1.226
Weed-free faba bean plants		0	57.00	10.83	19.28	3.67
LSD at 5%			2.08	0.66	1.17	0.200

Yield and yield components

The application of leaf and root extracts of *A. vera,* into the soil and/or by spraying indicated that the number of pods/plants, weight of seeds · plant^{-1} as well as weight of 100 seeds of faba bean plant were significantly greater than the unweeded control (Table 3). The number of seeds/pods was nonsignificant. Compared to unweeded pots the number of pods/plants, weight of seeds/plant (yield · plant^{-1}) and weight of 100 seeds in the pots incorporated with *A. vera* leaf extract at 10% followed by spraying the same extract at 20% showed the best results. It is worth mentioning that the yield/plant reached two-fold of the yield in unweeded control. In addition, the number of pods/plant as well as weight of 100 seeds reached 89.27 and 70.45% increases over the unweeded control, respectively. On the other hand, *S. oleraceus* competition (unweeded plants) reduced the number of pods/plants, weight of seeds/plant and weight of 100 seeds by 43.99, 47.54, 40.92%, respectively, in comparison to heathy plants.

Quantitative determination of bioactive materials

Data in Table 4 show that the phenol content in *A. vera* leaf and root extracts was the highest followed by alkaloids, flavonoids, saponins and tannins. It was observed that the concentration and percentage of bioactive materials in leaf extract was three times more than in root extract.

Data in Table 4 represent the concentration of bioactive materials as mg suitable stander · g^{-1} dry plant material.

Table 4. Some phytochemical compositions of *Aloe vera* leaf and root extracts

Phytochemical	Composition	
	leaves	roots
Total phenol (mg · g^{-1} dry weight)	30.5 ± 0.06	7.4 ± 0.01
Total flavonoids (mg · g^{-1} dry weight)	1.5 ± 0.077	0.4 ± 0.01
Tannins (mg · g^{-1} dry weight)	0.1 ± 0.02	0.03 ± 0.02
Alkaloids (%)	3.5 ± 0.01	1.5 ± 0.02
Saponins (%)	3.1 ± 0.02	1 ± 0.03

Antioxidant activity

The 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical is extensively used in assessing unfastened radical scavenging activity due to the ease of the reaction. DPPH scavenging was 75% in leaves while in roots it was 15% (Table 5).

Table 5. Antioxidant activity in *Aloe vera* leaf and root extracts

	Leaves	Roots
DPPH percentage	75%	15%

Discussion

Many plant species that produced and released secondary metabolites into the surrounding environment were documented to suppress the growth of neighboring plants (Roby *et al.* 2013).

Table 3. The effects of natural extracts of leaves and roots of *Aloe vera* on yield and yield components of faba bean (Mean of the two seasons)

Treatments		Concentration [%]	Number of pods · plant^{-1}	Number seeds · pod^{-1}	Wt of seeds · plant^{-1}	Wt of 100 seeds
Leaf extract	soil treatment + spray	10 + 10	5.66	2.66	11.78	98.55
		10 + 20	6.00	3.66	13.09	100.57
Root extract	soil treatment + spray	10 + 10	5.33	3.33	10.50	95.65
		10 + 20	5.50	3.66	11.40	98.45
Leaf extract	soil treatment	10	5.00	3.33	10.35	92.80
Root extract	soil treatment	10	5.00	3.33	10.03	89.76
Leaf extract	spray treatment	10	4.16	3.00	9.31	88.58
		20	4.66	3.00	9.77	81.38
Root extract	spray treatment	10	3.33	2.33	7.20	78.66
		20	4.00	2.66	9.23	61.22
Unweeded faba bean plants		0	3.17	2.33	6.30	59.00
Weed-free faba bean plants		0	5.66	3.33	12.01	99.87
LSD at 5%			0.52	NS	0.86	2.76

Wt – weight, NS – nonsignificant

The results of this investigation indicated that *A. vera* leaf and root extracts inhibited the growth of *S. oleraceus* weed associated with faba bean plants. The degree of inhibition depended on the type and method of extract application as well as concentration. The results revealed that more inhibition in the weed was introduced by the leaf extract especially with soil treatment sequenced by spray. Very significant inhibition in the growth of the weed at both vegetative and harvest stages was obtained by the application of soil (10%) sequenced by spray leaf extract at 20%.

Several consequences have documented strong allelopathic action of leaf and root extracts of *Aloe* species (Arowosegbe *et al*. 2012; El Sherif 2017; Ali *et al*. 2019). Alipoor *et al*. (2012) noted suppression within the germination and boom of wheat (*Triticum aestivum*) seedlings, cereal rye (*Secale cereale*), lawn cress (*Lepidium sativum*), redroot amaranth (*Amaranthus retroflexus*) and dandelion (*Taraxicum officinalis*) via ethanolic extract of *A. vera* leaf and vegetation at concentrations from 2.5 to 10. % The authors added that more reductions were obtained by leaf extract. In addition, Arowosegbe *et al*. (2012) found reduced germination of tomato seeds as well as inhibition in root and shoot elongations of tomato seedlings. The inhibition percentage increased with increasing concentrations of the extract. The mitotic index and the growth rate of *A. cepa* root were decreased in comparison to the control by *A. vera* gel extract (Ilbas *et al*. 2012). In addition, the aqueous leaf extract of *A. vera* inhibited *A. hybridus* germination completely at 10 and 25% and the root length was inhibited by all extract concentrations (1, 5, 10, and 25%) (Bendjedid *et al*. 2022). On the other hand, Ravlić *et al*. (2017) and Singh *et al*. (2019) mentioned that the leaf extract of *A. vera* reduced germination of *S. nigrum* L. emend Miller and *Commelina benghalensis* L. by 19.6%, while it had no effect on root length of weed species and stimulated shoot length, fresh and dry biomass of black nightshade, redroot pigweed and velvetleaf seedlings. However, the reduction or stimulation of plants and weeds by allelopathic extracts depend on the concentration of the allelopathic extracts as well as plant response (Zeng 2014). In general, several workers have documented that those medicinal plants showed allelopathic activity against other plant species (Azizi and Fujii 2006; Safari *et al*. 2010; El-Metwally and El-Rokiek 2019).

The results indicated that the leaf extract had more inhibitory action against *S. oleraceus* weed than root extract. In this respect, the leaf extract had stronger inhibitory potential than other plant parts for some other plants like *Parthenium hysterophorus* (Alipoor *et al.* 2012; El-Rokiek *et al.* 2022a). Previous work on *Moringa oleifera* extracts by El-Rokiek *et al*. (2022a) also confirmed the present results that leaf extract exerted more potential inhibitory action on *Echinochloa colonum* than other parts.

The stronger allelopathic effect of leaf extract than root extracts on *S. oleraceus* growth may be attributed to the higher concentrations of allelochemical materials such as phenolic compounds, flavonoids, alkaloids, tannins and saponins (Table 4). The leaves are the organs with the highest concentration of allelochemicals and so have a higher ability to inhibit weed development (Saludes-Zanfañ *et al*. 2022). Therefore, the results will be discussed according to this phenomenon. Table 4 reveals that total phenolic components, total flavonoids, total alkaloids, tannins and saponins contents in the leaf extract greatly exceeded their contents in the root extract. The leaf extract induced higher inhibition in the weed *S. oleraceus* than that caused by the root extract which may indicate that these allelochemicals cause weed inhibition. Different workers have confirmed these results (El-Rokiek *et al.* 2016; Ghimire *et al.* 2020; Kato-Noguchi and Kurniadie 2022). Chaudhuri and Ray (2016) reported that tannic acid and phenolic components may be considered as substitutes of chemical herbicides. Similar results were documented by Ghimire *et al*. (2020) on fresh and dry biomass of *Commelina communis*, *Artemisia princeps* var. orientalis, *Bidens frondosa* and *Oenothera biennis* by *Miscanthus sacchariferous* water extract. The authors linked the reduction of weed growth with the presence of different phenolic compounds. Kato-Noguchi and Kurniadie (2022) and El-Rokiek *et al*. (2022a) and Jabeen *et al.* (2023) obtained similar results, thus these documents coincided with the present work. In previous research (El-Rokiek *et al.* 2022b) found that bitter lupin seed extract had higher reduction on canarygrass (*Phalaris minor*) than sweet lupine seed extract. The authors attributed the higher reduction in weed growth to the high content of alkaloids. This suggestion also confirmed the current results. Other suggestions by Mahalel (2015) confirmed the present results that saponins extracted from alfalfa, *Trigonella hamosa* and *S. lycopersicum* significantly reduced germination and seedling growth of wheat, corn and barnyard grass as well as *A. cepa*.

The results also showed that root extract had antioxidant activity (15%), while 75% antioxidant activity was determined in the leaf extract. Antioxidants are secondary metabolites as total phenol that can protect cells from damage caused by free radicals and can react with superoxide anions and lipid peroxyl radicals and so inhibit lipid peroxidation (Li *et al*. 2021).

The inhibition of weed growth resulted in less competition between the target plant (herein faba bean) and the weed (*S. oleraceus*), so, the more nutrients absorbed by the plant, the more water was taken. According to this low competition increases in the growth and yield of faba bean were obtained. Many workers have demonstrated that controlling weeds decreased the competition between weeds and the target crop and consequently the desired increase in the growth and yield of crops was obtained (El-Metwally and El-Rokiek 2019; Messiha *et al*. 2021; El-Rokiek *et al*. 2022a, b).

Conclusions

The weeds' growth and development may be impacted by the bioactive components (phenolic compounds, flavonoids, alkaloids, tannins, and saponins) found in the *Aloe vera* leaf and root extracts. The majority of natural goods' structural varieties might have an allelopathic impact. By preventing the growth of nearby plants, allelopathy in agricultural plants can aid in preventing weed growth and boost the competitiveness of invading plant species. Therefore, *Aloe vera* leaf and root extracts might be regarded as a source of bioherbicides.

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