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Allelopathic Activity of Coriander (Coriandrum Sativum L.)

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Abstract

In recent years there has been increased interest about the allelopathic effects of plant extracts used as bioherbicides, in order to manage weeds with a decreasing use of herbicides. An interesting crop, from an allelopathic point of view, is coriander (*Coriandrum sativum* L.), a medicinal plant member of Apiaceae family. The aim of this study was to evaluate the allelopathic activity of coriander against a possible succeeding crop, like wheat (*Triticum aestivum*L.), and against some weeds, like *Lolium multiflorum* Lam., *Sinapis alba* L. and *Amaranthus retroflexus* L., ubiquitous in the Mediterranean agroecosystems. In Petri dish bioassays, seeds of above mentioned species were treated with 0, 2.5, 5, 10, 17.5, 25 % w/v concentrations of aqueous extracts from leaves, stems and roots of coriander at flowering and maturity growth stage. The ranking among different extracts based on their allelopathic effects was: leaves extract > stems extract > roots extract. The allelopathic activity of coriander at maturity stage decreased with respect to that at flowering stage. The aqueous extracts from aerial biomass of coriander inhibited the seed germination of weeds, but not that of *T. aestivum*. This research has provided interesting scientific insights into the allelopathic activity of coriander in weed management, however other aspects need to be further investigated.

INTRODUCTION

Allelopathy is an ecological phenomenon that encompasses the positive and negative effects that one plant exerts on another one through the release of chemical compounds (allelochemicals) into the environment and it has significant implications for natural ecosystems and agroecosystems (Rice, 1984). Allelochemicals are secondary metabolites produced by plants that influence the biology of neighbouring organisms, with important ecological and agricultural implications (Li et al., 2010; De Crescenzo, 2014). Understanding this phenomenon is crucial for the development of sustainable agricultural practices (Mallik, 2008). Among the most studied aspects there are the outcomes on crop diseases and especially towards weeds, in order to understand the mechanisms and develop possible practical implications for the benefit of farmers, through the inclusion of allelopathic species in rotation, or direct application of plant derivatives. In fact, it is possible to exploit allelopathic effects in weed control, thus reducing the use of herbicides and promoting integrated and organic management in crop systems (Bhowmik and Inderjit, 2003; Weston and Inderjit, 2007; Nelson et al, 2012; Pannacci et al., 2017).

In recent years there has been increased interest about the allelopathic effects of plant extracts used as bioherbicides, in order to discover and understand the allelopathic potential towards weeds, as well as towards the main cultivated crops, with the main purpose of decreasing the use of synthetic herbicides through this possible alternative control tool (Farooq et al., 2011; Soltys et al., 2013). In this regard, the hypothesis is accepted that weeds are most inhibited by allelochemicals at the seed stage or early growth stages, while being less susceptible at late growth stages (Kruse et al., 2000).

The growing interest in alternative weed management methods to herbicides stems from the increasingly frequent cases of resistance by weeds to the most popular active ingredients and modes of action of herbicides. In fact, with chemical control, strong selective pressure is exerted in favour of weed genotypes that are resistant to the active ingredients used, consequently reducing the effectiveness of subsequently applied treatments (Abbas et al., 2018).

In Italy, for example, glyphosate-resistant populations have been found belonging to three species, *Lolium multiflorum* Lam. (also in biotypes with cross-resistance to HRAC groups A and B), *Erygeron canadiensis* L., and *Lolium rigidum* Gaudin (Heap, 2024). These populations were found in Apulian olive groves and Piemontese vineyards, agroecosystems where there is strong selective pressure due to the absence of rotations and almost exclusively chemical control with repeated applications of a single broad-spectrum total herbicide. In 1999, biotypes of common amaranth (*Amarantus retroflexus* L.) were found to show cross-resistance to HRAC C1 group herbicides in maize, soybean, and sugar beet; the same weed also showed resistance to the action of group B herbicides in soybean agroecosystems (Heap, 2024).

In a national and global context in which cultivated crops, both major and minor, are increasingly subject to competition from weeds resistant to the most common herbicides modes of action, it turns out to be of paramount importance to develop an Integrated Weed Management System (IWMS) aimed at the implementation of measures that are both proactive, i.e., aimed at disfavouring weed establishment, growth and competition, and reactive, i.e., direct and specific actions following the onset of the competitive problem (Zanin et al., 2024). In this regard, knowledge about allelopathic interactions can provide information both for a proper setting of the cropping system, with proactive measures, and find possible applications in reactive measures, contributing to the environmental and economic sustainability of production processes (Zanin et al., 2011).

Closely related to allelopathic interactions, the success of practices such as crop rotations or intercropping turn out to be strongly influenced by the presence of allelochemicals (Scognamiglio et al., 2013). Among the possible applications of these substances we also have their direct use in the form of aqueous extracts at different dosages obtained from crops with allelopathic effects toward certain weeds, applicable through direct distribution in the field, a solution that turns out to be a viable practice from both the environmental and economic points of view (Jamil et al., 2009; Maurya et al., 2024).

In this context, a crop of interest from an allelopathic point of view is coriander (*Coriandrum sativum* L.), a medicinal plant with a short 4-month cycle, it belongs to the Apiaceae family. It is an annual herb with origins from the Mediterranean area but widely cultivated in North Africa, Central Europe and Asia as a medicinal and food essence, that grows excellently in a wide range of environmental conditions (Hammer, 2004; Seidemann, 2005). Coriander prefers cool, well-drained soils with pH between 6 and 7, suitable for warm-temperate climates with optimum germination temperatures around 12–15°C; sowing is done in spaced rows with cereal seeder machine between March and April (Diederichsen, 1996). Harvesting takes place between July and August on senescent plants through the use of harvesters,

taking into consideration the degree of scalar ripening and drying of the fruits, which tend to shatter during the harvesting stage thus affecting yield and quality (Diederichsen, 1996). Coriander has important pharmaceutical properties, but has received little attention from the allelopathic point of view in plant-plant interactions, resulting in a scarce supporting bibliography. For example, Dhima et al. (2009) demonstrated the allelopathic potential of coriander through experiments conducted both in the laboratory and in the open field, with comparative evaluation with other aromatic species. The authors recorded a decrease in the number of plants and fresh weight of *Chenopodium album* L. and a decrease in the number of plants of *Tribulus terrestris* L. reporting a consequent significant increase in both grain and silage production obtained from coriander compared to the untreated control. In the same trial, however, seeds of *Portulaca* spp. and *Echinochloa* spp. were found to be less inhibited. In a subsequent publication, it was indicated that coriander essential oil, under laboratory conditions, results in moderate inhibition on *Echinochloa* spp. when compared to those of essential oils of basil (*Ocimum basilcum* L.) and fennel (*Foeniculum vulgare* P. Mill.), while in the field the suppression was also found to be strongly greater due to the good competitive performance of the species compared to the other aromatics tested (Dhima et al., 2010).

However, there are no studies on the allelopathic activity of coriander aimed at typical species in Mediterranean agroecosystems, whose research could represent an important step towards more sustainable weed management. Therefore, the aim of the present study was to evaluate the allelopathic activity of coriander (*Coriandrum sativum* L.) against a possible succeeding crop, like wheat (*Triticum aestivum* L.), and against some weeds, like *Lolium multiflorum* Lam., *Sinapis alba* L. and *Amarantus retroflexus* L., ubiquitous in the Mediterranean agroecosystems.

MATERIALS AND METHODS

Plant sampling and aqueous extracts preparation

Plants of coriander (*Coriandrum sativum* L.) were collected from a cultivated field in a farm located in Collelungo, Castiglion del Lago (Perugia), central Italy (43°04’N, 12°02'E, 300 m a.s.l.), at two different growth stages: i) flowering stage; ii) harvest maturity stage. Fresh coriander plants at flowering stage were separated into leaves, stems and roots, while at harvest maturity stage, the plants were separate into aerial biomass (leaves + stems) and roots, due to their senescence conditions. The plant materials were dried in a hot-air oven at 45°C for 5 days, ground with an electrical grinder, sieved through a 1 mm sieve, and kept in a dry and dark bag at 10°C for future use. Each different plant materials (leaves, stems, roots and aerial biomass) were soaked in distilled water for 24 h at 24°C in laboratory to give concentration of 25 g of dry tissue per 100 ml of water (25% w/v). After soaking, the aqueous solutions were filtered through 4-layer of cheesecloth to remove the fibre debris and then the aqueous extracts were filtered again through filter paper and used as stock extracts in the Petri dish bioassays.

Petri dishes Bioassays

Petri dish bioassays were carried out according to the methodology already showed by Pannacci et al. (2015; 2013). Seeds of white mustard (*Sinapis alba* L., cv. Max), wheat (*Triticum aestivum* L., cv. Bilancia), Italian ryegrass (*Lolium multiflorum* Lam., cv. Devis) and redroot pigweed (*Amaranthus retroflexus* L.) were pre-sterilized with 2% sodium hypochlorite for 5 min. and washed with distilled water. Fifty seeds of each spe-cie were evenly placed on filter paper in sterilized separate 120-mm Petri dishes. Each stock extract was diluted with distilled water to prepare 0, 2.5, 5, 10, 17.5, 25% w/v concentrations, these were added at 7 mL per Petri dish. The treatments were replicated thrice according to a completely randomised design. All Petri dishes in bioassays were placed in a growth chamber at dark, with temperature of 20°C. Germinated seeds were counted after 10 days in all species and ten representative seedlings per Petri dish were chosen to determine the radicle and hypocotyl lengths in all species. Furthermore, in *Sinapis alba* L. also fresh weight of seedling was measured. Data on seed germination, radicle length, hypocotyl length and weight of seedlings were converted to percentage relative to untreated control (Abbott, 1925).

STATISTICAL ANALYSIS

Bioassays data were subjected to non-linear regression analyses by using the log-logistic model proposed by Streibig et al. (1993):

$$Y = C + \frac{D - C}{1 + exp\left\{b\left[log\left(X\right) - log\left(a\right)\right]\right\}}$$

1

where Y is the response (i.e. percentage of seed germination, radicle length, hypocotyl length and weight of seedlings) of the test specie as a function of the extract concentration X, D is the upper asymptote (response of the untreated control), C is the lower asymptote (response at extremely high concentration), a is the concentration that give a response half way between upper and lower asymptotes and b is the slope around the inflection point.

In some cases, growth stimulation was observed at low concentration doses, hence, following peaked model was used (Brain and Cousens, 1989):

$$Y = C + \frac{D - C + fX}{1 + exp\left\{b\left[log\left(X\right) - log\left(a\right)\right]\right\}}$$

2

where, ƒ is the parameter for stimulation.

Fitted equations were used to calculate the extract solution concentration required to give 50% and 90% reduction of the control value in terms of seed germination, radicle or meso/hypocotyl length of seedlings, i.e. EC50 and EC90 (effective concentration) (Pestemer and Günther, 1995). The assumption that dose-response curves could be fitted to the data was assessed by an F-test for lack-of-fit comparing

the residual sum of squares of an analysis of variance and the non-linear regression (Ritz and Streibig, 2005).

The models were fitted to the experimental data using the EXCEL® Add-in macro BIOASSAY97 (Onofri e Pannacci, 2014).

RESULTS AND DISCUSSION

Allelopathic activity of leaves, stems and roots aqueous extracts of coriander at two different growth stages on S. alba

The coriander plants sampled at flowering stage showed the following humidity values of the different parts: leaves (76.1%); stems (79.9%); roots (78.3%). Furthermore, their percentage distribution on the weight of the whole plant was as follows: leaves (17.8%); stems (73.4%); roots (8.8%). The coriander plants sampled at harvest maturity stage showed the following humidity values of the different parts: aerial biomass (12.7%); roots (14.7%). These values showed a prevalence of the stems over the other parts (leaves and roots), in the external plant structures at the flowering stage, while the humidity of the plant was reduced to lower values at the harvest maturity stage, due to plant senescence that allows the mechanical harvest of seeds.

In the bioassay with *Sinapis alba* L., leaves, stems, roots and aerial biomass aqueous extracts of coriander at the two different growth stages inhibited seed germination, radicle length, hypocotyl length and weight of seedlings in this test specie (Figs. 1 and 2). Dose-response curves showed as the degree of inhibition increased with the extract concentration, according to the log-logistic model (Eq. 1), although, in some cases, data were well adapted to peaked model (Eq. 2). The EC50 and EC90 values were always well estimated from the dose-response curves, except, in some cases, because outside to the range of tested extract concentrations (Table 1).

At the flowering stage, leaves extract showed higher allelopathic effects than stems and roots extracts, inhibiting more severely seed germination and seedling growth of the test specie (Fig. 1). In particular, EC values of leaves extract were always lower than those of stems and roots extract, showing to be able to reduce of 50% all the parameters of test specie, with a concentration ranging from 3–7.7% w/v (Table 1). Stems extracts showed EC values always lower than those of roots extract, although these differences were not always statistically significant (Table 1). Based on these results, therefore, the ranking among different extracts based on their allelopathic effects to inhibit seed germination and seedling growth of S. alba was: leaves extract > stems extract > roots extract (Fig. 1; Table 1). The highest allelopathic activity in leaves with respect to stems and roots was observed in other species, such as *Helianthus annuus* L. (Pannacci et al., 2013; Ashrafi et al., 2008), *Artemisia vulgaris* L. (Pannacci et al., 2015; Barney et al., 2005), and *Cannabis sativa* L. (Patanè et al., 2023). Allelopathic activity of coriander against seed germination and seedling growth of weeds and crops was observed by other authors (Iqbal et al., 2015; Ravlić et al., 2013).

At harvest maturity stage of coriander, allelopathic inhibitory effects of water extracts of aerial biomass were higher than those of roots extract, confirming the results obtained at flowering stage (Fig. 2). Furthermore, the inhibitory effects were more pronounced on seedling growth (hypocotyl length, radicle length and seedling weight) than on seed germination (Fig. 2; Table 1). The allelopathic activity of coriander at harvest maturity decreased with respect to that of coriander at flowering stage, otherwise the biostimulation effects, due to hormetic phenomena, increased, especially for hypocotyl length (Figs. 1 and 2; Table1). In fact, in the dose-response curves, the values of stimulation parameter f were always statistically significant ($P < 0.05$) (data not shown) and EC values increased out the range of the investigated aqueous extracts concentrations (> 25% w/v) (Table 1). This stimulation phenomenon has been observed in plants with allelopathic extracts applied at low concentrations and their applications as potential biostimulants, from an agricultural point of view, have been investigated (Godlewska et al., 2021; Pannacci et al., 2022). In this case, the aqueous extracts of coriander at harvest maturity stage were probably characterized by lower allelochemicals than those at flowering stage, allowing to stimulate growth of hypocotyl, radicle and weight of S. alba seedlings when applied at low concentration (5% w/v). These results are supported by Telci et al. (2006) that found as, in coriander, essential oil contents of premature fruits were higher than that of ripened fruits. Similar findings in the variation of essential oil contents at different growth stages of coriander were reported by Al-Khayri et al. (2023). Furthermore, it is well documented that concentrations of allelochemicals in living plants decrease with the age of the plant (An et al., 2003). For these reasons, the higher allelopathic activity of the aerial parts (leaves and stems) of coriander at flowering stage, could suggest its potential harvesting as a whole plant at this stage, with the aim of obtaining aqueous extracts to be applied directly in the field as pre-emergence bioherbicides. This utilization has already been demonstrated by some authors with coriander (Dhima et al., 2009) and with other species (Pannacci et al., 2015). In this regard, harnessing the allelopathic activity of coriander could find a valuable application in managing weed infestations in vegetable and minor crops, where the availability of herbicides is very limited (Pannacci et al., 2017). In particular, the choice of transplanted vegetable crops instead of direct-seeded ones, which can follow coriander in crop rotations, such as fennel, radicchio, cabbage, etc., could help to reduce any potential negative allelopathic effects on crop germination. This is based on studies by Kruse et al. (2000), which have shown that plants are more sensitive to allelopathic substances at the seed stage, whereas they become less sensitive if these substances are present in the rhizosphere during subsequent stages of development. Furthermore, the results obtained allow us to assert that the use of coriander as a seed crop, harvested at full maturity, not only represents income for the farmer but also leaves crop residues (aerial and root parts) in the soil with allelopathic activity. These residues are potentially capable of inhibiting the germination and growth of weeds in subsequent crops. However, in order to apply these finding in an integrated weed management system, more knowledge needed, especially about the effects in the field experiments applications (Jabran et al., 2015). In the absence of data in this regard, it is still important to note that in the agricultural company, from which the coriander biomass was taken for this experimentation, the crops used in succession to coriander, have consistently shown reduced weed presence, with evident benefits in terms of growth and yields (Bartocci, personal communication).

Allelopathic activity of aerial biomass (leaves + stems) aqueous extracts of coriander at flowering stage on T. aestivum and weeds

The aqueous extracts from aerial biomass (leaves + stems) of coriander inhibited the seed germination of *L. multiflorum* and *A. retrofluxus*, but not that of *T. aestivum* (Fig. 3a and Fig. 4a,c). In particular, the inhibition of seed germination of weeds (*L. multiflorum* and *A. retroflexus*) was severe at the two highest extract concentrations (17.5% and 25% w/v), whereas, at the lowest concentrations, seed germination of *A. retroflexus* was greatly stimulated (Fig. 4c), with a significant stimulation parameter value ($f = 28.5 \pm 0.82$, $P < 0.001$). Stimulation effect at the lowest extract concentrations was also observed on the hypocotyl length of *A. retroflexus* ($f = 27.8 \pm 4.2$, $P < 0.001$), whereas the radicle length was strongly inhibited (Fig. 4d; Table 2). *A. retroflexus* showed similar effects when treated with aqueous extract of aerial biomass of mugwort (*Artemisia vulgaris* L.), although in this case seed germination was severely inhibited and not stimulated by the lowest extract concentrations (Pannacci et al., 2020).

CONCLUSIONS

The results obtained allow us to draw the following conclusions: i) at flowering stage, the leaves of *C. sativum* exhibit greater allelopathic activity compared to the stems and roots, with the following decreasing ranking: leaves > stems > roots; ii) *C. sativum* could be used as “dead mulching” or as an intercropping crop to be chopped and buried at flowering stage, before a main crop, to help control weed emergence; iii) *C. sativum* could be harvested as a whole plant at flowering stage to obtain aqueous extracts that can be directly applied in the field as pre-emergence bioherbicides in organic farming; iv) the allelopathic activity of *C. sativum* tends to decrease as the phenological stage progresses, although it remains present even at the crop's maturity stage; v) the use of coriander as a seed crop, besides representing an income for the farmer, leaves crop residues with allelopathic activity in the soil, potentially able to inhibit the germination and growth of weeds in successive crops; vi) from practical experience, crops sowed in succession to coriander benefit from it, both in terms of reduced weed presence and in terms of growth and yields.

This research has provided interesting scientific insights into the allelopathic activity of *C. sativum* and its potential use in weed management. However, other aspects need to be further investigated, as: i) expand knowledge on the effects of *C. sativum* aqueous extract on more potential successive crops and their associated weeds; ii) investigate the bioavailability of the extract in the soil; iii) analyse the *C. sativum* extracts to define their allelochemicals composition; iv) study the effects of individual allelochemicals contained in the extracts that are potentially responsible for the allelopathic phenomena, with the aim of using them as precursors for the synthesis of herbicides with new modes of action.

Declarations

Author contributions

Conceptualization: [Euro Pannacci]; Methodology: [Euro Pannacci], [Giulia Contini]; Data curation: [Euro Pannacci], [Giulia Contini]; Formal analysis and investigation: [Euro Pannacci], [Giulia Contini]; Writing - original draft preparation: [Euro Pannacci], [Vittorio Monni]; Writing - review and editing: [Euro Pannacci], [Vittorio Monni], [Francesco Tei]; Supervision: [Euro Pannacci], [Francesco Tei]

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Tables

Table 1. EC_{50} and EC_{90} values (% w/v) of leaves, stems, roots and aerial biomass aqueous extract of coriander at flowering and harvest maturity stages, on germination, radicle length, hypocotyl length and seedling weight of *S. alba*, extrapolated from dose-response curves showed in figures 1 and 2 (standard errors and confidential intervals are in parentheses).

Growth stage	Extract	Seed germination		Radicle length		Hypocotyl length		Seedling weight	
		EC_{50}	EC_{90}	EC_{50}	EC_{90}	EC_{50}	EC_{90}	EC_{50}	EC_{90}
Flowering	leaves	7.7 *(0.21)*	11.5 *(0.40)*	3.0 *(0.12)*	9.6 *(0.78)*	3.3 *(0.14)*	7.7 *(0.72)*	4.6 *(0.39)*	14.7 *(2.68)*
	stems	12.4 *(0.36)*	15.4 *(0.82)*	5.1 *(0.30)*	12.7 *(2.04)*	11.1 *(1.33)*	12.8 *(2.03)*	10.8 *(1.02)*	11.6 *(1.04)*
	roots	17.4 *(0.19)*	20.8 *(2.26)*	5.8 *(0.39)*	14.4 *(2.04)*	10.6 *(1.09)*	22.4 *(4.76)*	12.3 *(1.01)*	> 25
Harvest maturity	aerial biomass	> 25	> 25	12.3 *(0.29)*	25.0 *(1.23)*	17.8 *(19.5-9.1)*	> 25	18.0 *(18.5-9.3)*	> 25
	roots	> 25	> 25	15.2 *(0.88)*	> 25	> 25	> 25	> 25	> 25

Table 2. EC_{50} and EC_{90} values (% w/v) of aerial biomass (leaves + stems) aqueous extract of coriander at flowering stage, on seed germination and seedling growth (radicle and hypocotyl length) of *T. aestivum*, *L. multiflorum* and *A. retroflexus*, extrapolated from dose-response curves showed in figures 3 and 4 (standard errors are in parentheses).

Specie	Seed germination		Radicle length		Hypocotyl length	
	EC_{50}	EC_{90}	EC_{50}	EC_{90}	EC_{50}	EC_{90}
T. aestivum	> 25	> 25	10.3 *(0.40)*	17.7 *(2.09)*	11.6 *(0.67)*	22.9 *(2.30)*
L. multiflorum	10.8 *(0.51)*	12.0 *(0.98)*	7.9 *(0.68)*	16.4 *(2.70)*	10.7 *(0.74)*	12.2 *(1.24)*
A. retroflexus	11.5 *(1.21)*	14.4 *(1.83)*	4.5 *(0.16)*	11.7 *(0.91)*	6.9 *(0.48)*	11.9 *(0.47)*

Figures

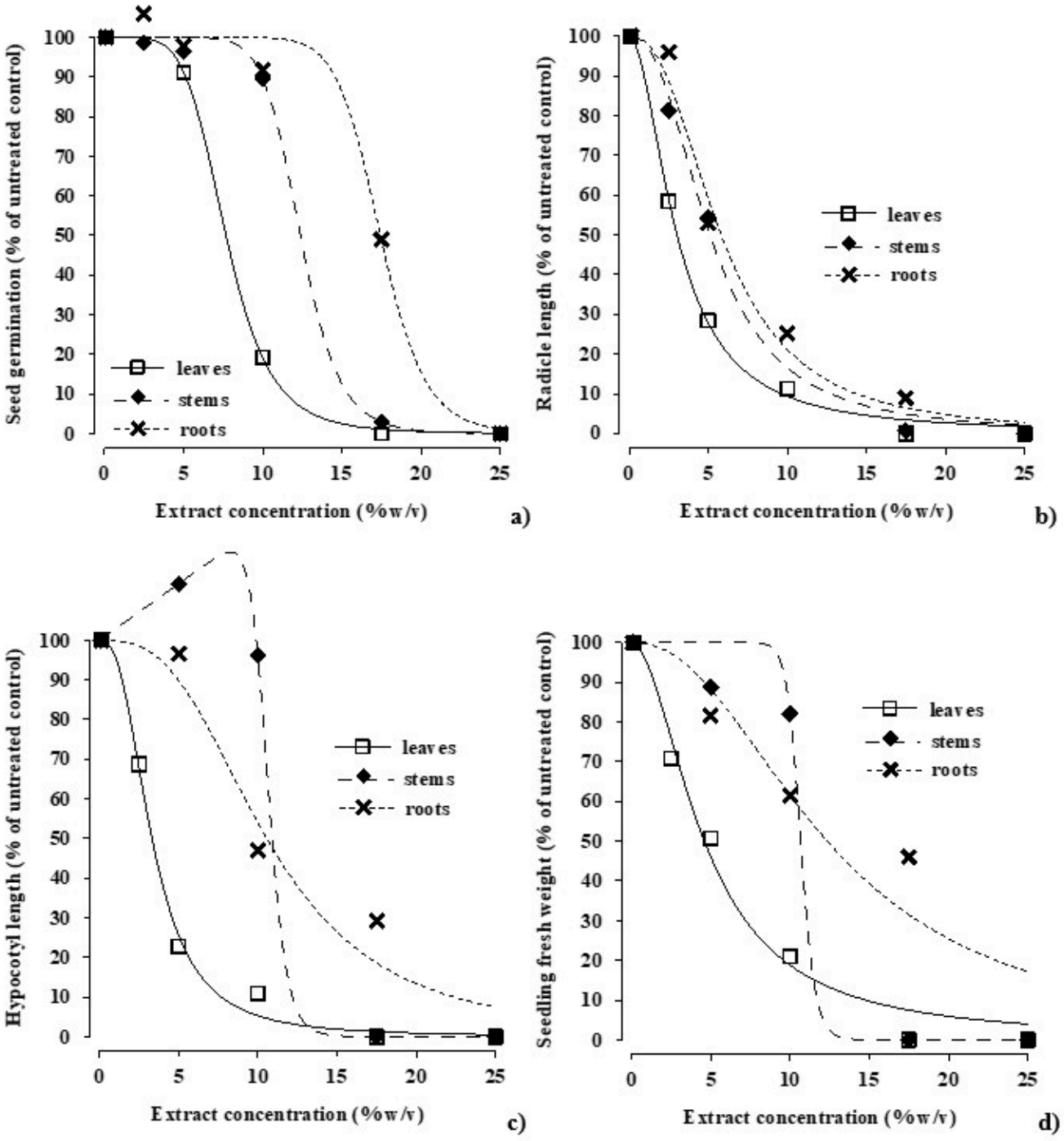


Figure 1

Effects of leaves, stems and roots aqueous extracts of coriander at flowering stage on seed germination (graphic a), radicle length (graphic b), hypocotyl length (graphic c) and seedling weight (graphic d) of *S. alba* (test specie). Symbols show observed data, lines show fitted curves according to model 1 and 2.

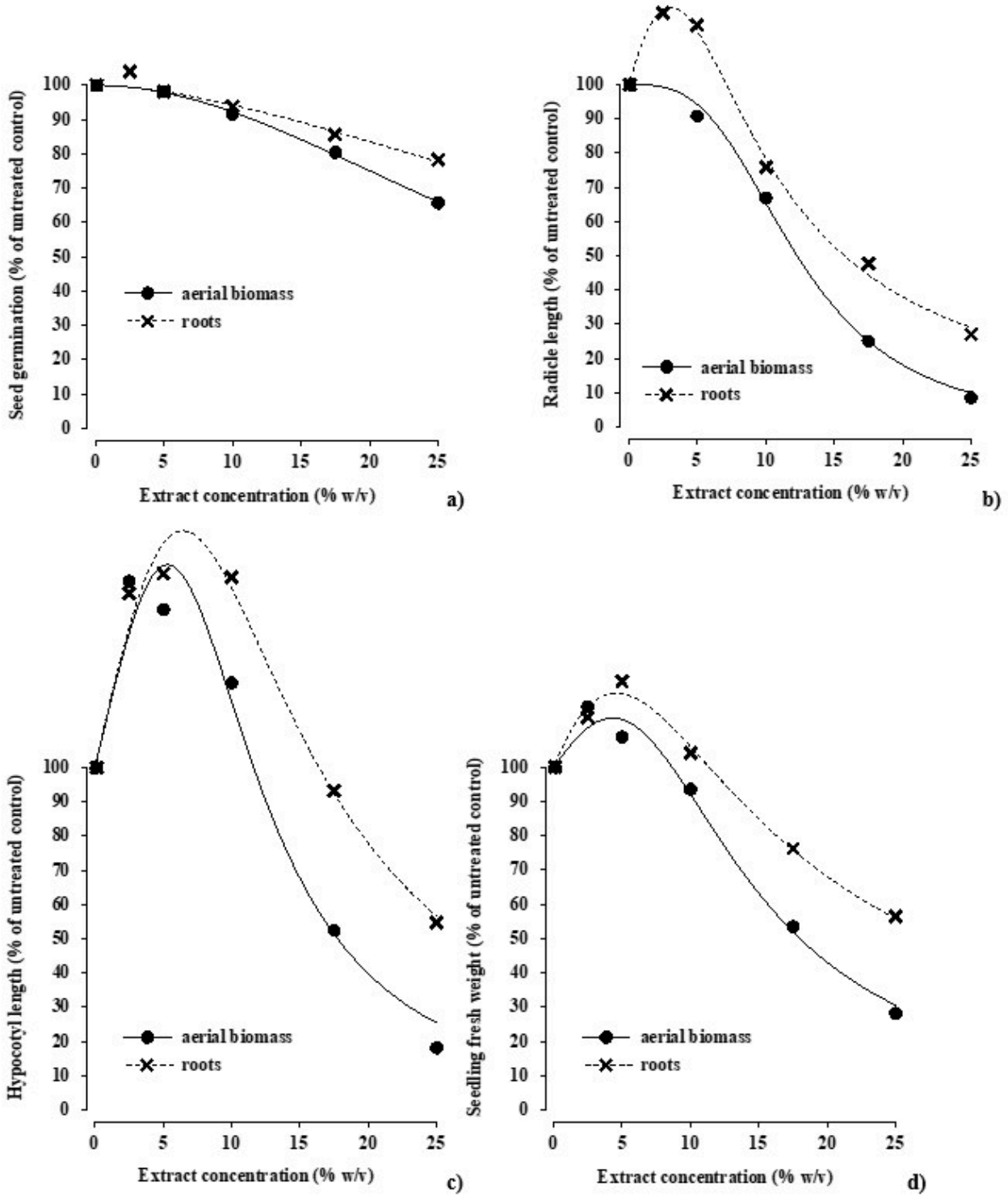


Figure 2

Effects of aerial biomass and roots aqueous extracts of coriander at harvest maturity stage on seed germination (graphic a), radicle length (graphic b), hypocotyl length (graphic c) and seedling weight (graphic d) of *S. alba* (test specie). Symbols show observed data, lines show fitted curves according to model 1 and 2.

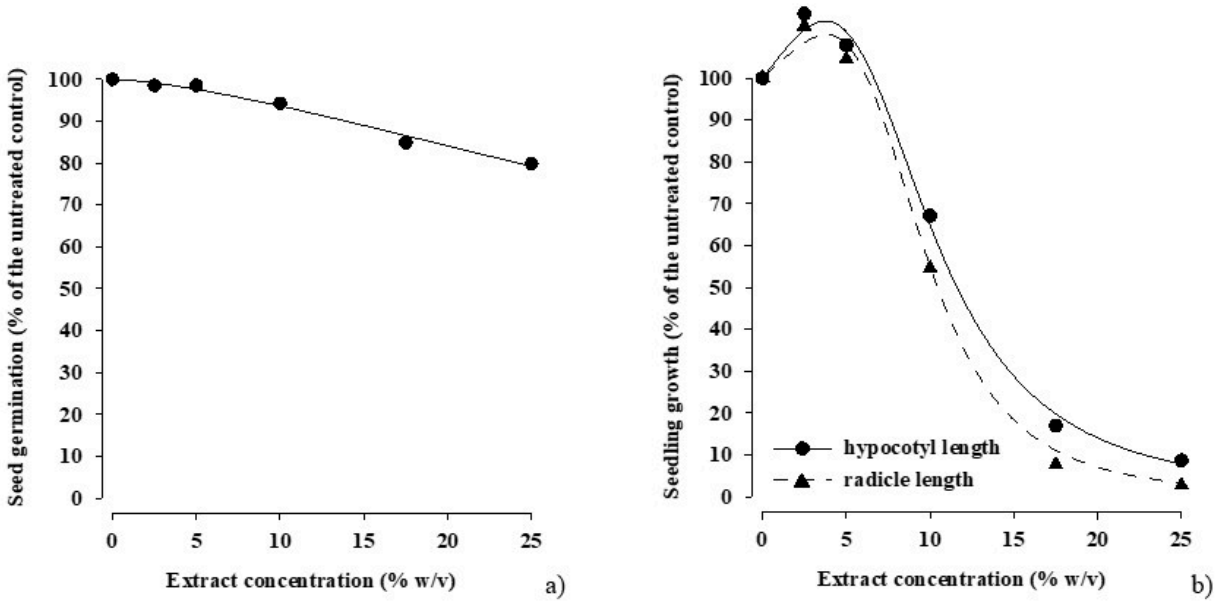


Figure 3

Effects of aerial biomass (leaves + stems) aqueous extracts of coriander at flowering stage on seed germination (graphic a) and seedling growth (hypocotyl and radicle lengths, graphic b) of *T. aestivum*. Symbols show observed data, lines show fitted curves according to model 1 and 2.

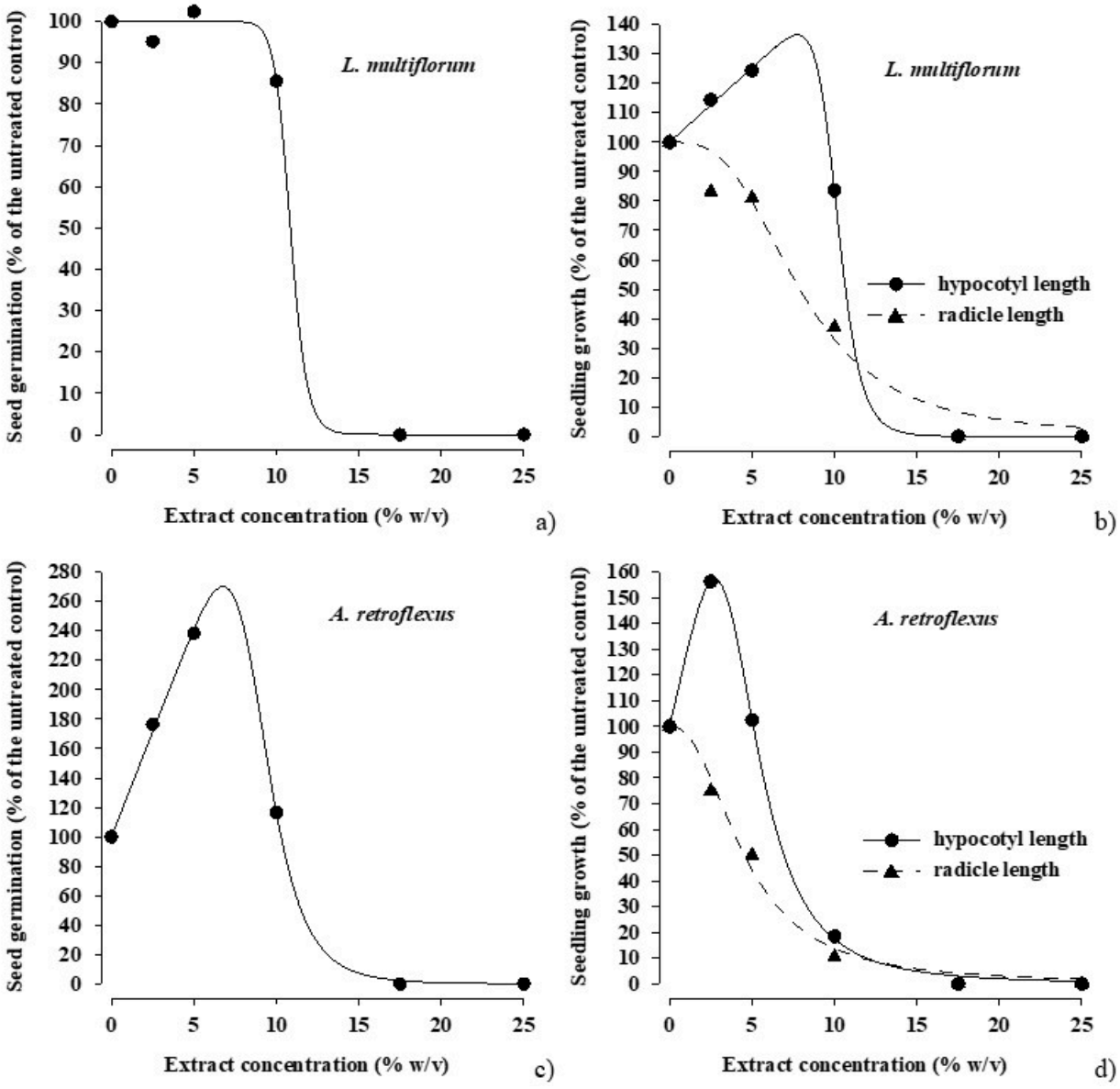


Figure 4

Effects of aerial biomass (leaves + stems) aqueous extracts of coriander at flowering stage on seed germination (graphic a and c) and seedling growth (hypocotyl and radicle lengths, graphic b and d) of *L. multiflorum* and *A. retroflexus*. Symbols show observed data, lines show fitted curves according to model 1 and 2.