



Evaluation of the allelopathic effect of *Sinapis arvensis* on the germination and growth of seedlings of *Triticum durum* and *Hordeum vulgare* under controlled conditions

Mohamed Abbad¹; Amina Djerdjouri² and Nedjouda Zemouri³

1. Laboratory of Plant Production and Biotechnology, Faculty of Nature and Life Sciences, Department of Biotechnology and agroecology, University of Blida 1, BP 270, Route of Soumaâ, Blida, Algeria

2. Laboratory of Genetic Resources and Biotechnology, Higher National School of Agronomic, El-Harrach, Algeria.

3. Laboratoire de aromatique and Medicinal plants. B.P. 270, Route of Soumaâ, Blida, Algeria.

Résumé

The effect of aqueous extracts from the leaves and roots of *Sinapis arvensis* (donor species, Brassicaceae) on the germination and growth parameters of durum wheat (*Triticum durum*) and barley (*Hordeum vulgare* L.) (recipient species, Poaceae) was evaluated. Experiments were conducted under controlled conditions over a 10-day period using various extract concentrations (0.25%, 50%, 75%, and 100%). Results showed that final germination rates (GR%) of both *T. durum* and *H. vulgare* seeds declined with increasing extract concentration, with the strongest effect observed in *H. vulgare* exposed to pure root extract (40.47%) compared to *T. durum* (10.52%). Pure leaf extracts of *S. arvensis* had a more pronounced inhibitory effect on coleoptile and radicle lengths of *T. durum* (reductions of 89.83% and 91.43%, respectively) than root extracts (77.80% and 78.12%, respectively). Fresh biomass of radicles and coleoptiles after 10 days was also more affected in *T. durum* by the foliar extract than in *H. vulgare*. Regression analyses indicated reductions of 99% and 60% in radicle fresh biomass for *T. durum* and *H. vulgare*, respectively, under foliar extract treatment, while root extracts caused reductions of 80% and 61.53%, respectively. These findings highlight the allelopathic potential of *S. arvensis* as a promising candidate for sustainable weed management through bioherbicide applications.

Mots clés : Allelopathic, *Sinapis arvensis*, germination, radicle, coleoptile, aqueous extract.

Évaluation de l'effet allélopathique de *Sinapis arvensis* sur la germination et la croissance des plantules de *Triticum durum* et *Hordeum vulgare* en conditions contrôlées

Abstract

L'effet des extraits aqueux issus des organes foliaires et racinaires de *Sinapis arvensis* (espèce donneuse, Brassicaceae) sur la germination et certains paramètres de croissance du blé dur (*Triticum durum*) et de l'orge (*Hordeum vulgare* L.) (espèces réceptrices, Poaceae) a été évalué. L'expérimentation a été menée dans des conditions contrôlées à travers des tests biologiques sur une période de dix jours, en utilisant différentes concentrations d'extraits (0,25 %, 50 %, 75 % et 100 %). Les résultats ont montré que les taux finaux de germination (GR%) des graines de *Triticum durum* et *Hordeum vulgare* diminuaient à mesure que la concentration en extrait aqueux augmentait. Cette diminution était plus marquée chez *H. vulgare* avec l'extrait racinaire pur (40,47 %) que chez *T. durum* (10,52 %). Cependant, l'extrait pur provenant de la partie foliaire de *Sinapis arvensis* a significativement affecté la longueur du coleoptile et de la radicule de *T. durum* (réductions de 89,83 % et 91,43 %, respectivement), comparativement à l'extrait pur de la partie racinaire (77,80 % et 78,12 %, respectivement). De plus, la biomasse fraîche des radicules et des coleoptiles des graines de *T. durum* après dix jours de germination a également été plus affectée par l'extrait foliaire pur de *Sinapis arvensis* que celle des graines de *H. vulgare*. Les analyses de régression ont montré des réductions de 99 % et 60 % de la biomasse fraîche des radicules de *T. durum* et *H. vulgare*, respectivement, en présence de l'extrait foliaire pur, tandis que les réductions atteignaient 80 % et 61,53 % pour les extraits racinaires des mêmes espèces. Sur la base de ces résultats, le potentiel allélopathique de l'espèce invasive étudiée est suggéré comme une option viable pour une gestion durable des mauvaises herbes à travers l'application de bioherbicides.

Keywords: Allélopathie, *Sinapis arvensis*, germination, radicule, coleoptile, extrait aqueux

¹ Corresponding author: abbadmohammed@gmail.com

INTRODUCTION

Cereals are a staple food in many developing countries, particularly in the Maghreb region. In Algeria, cereal crops hold a strategic position in the national food system and economy. They occupy approximately 80% of the country's useful agricultural area (UAA), with 3 to 3.5 million hectares cultivated annually, of which only 63% is harvested [1]. Despite this, cereal production remains insufficient to meet the growing demand and is highly dependent on climatic conditions, leading to significant annual variations in cultivated area, production, and yield. In particular, insufficient rainfall and its uneven distribution during the growing season are major factors affecting cereal production. Declining soil fertility and irregular rainfall during crop growth and maturation are major constraints to yield improvement in the Mediterranean region of North Africa [2]. Beyond the classical competition for water, nutrients, and light, recent studies have highlighted the role of chemical interactions, known as allelopathy, which can influence crop growth and weed control. Many plant species produce molecules capable of affecting neighboring plants by inhibiting germination and growth [3].

Chemical interactions in agroecosystems can significantly impact productivity [4], involving allelochemicals released through volatilization, leaching, decomposition of plants tissues, or root exudation [5]. Most allelochemicals are secondary metabolites, which may have either inhibitory or stimulatory effects on surrounding plants [6], affecting membrane permeability, water and nutrient uptake, and overall growth [7]. Studies have shown that allelopathic compounds can inhibit seed germination and seedling development, with effects that may be additive or synergistic [8].

The objective of this study was to evaluate the allelopathic effects of aqueous extracts from different parts of *Sinapis arvensis* on the germination and growth of durum wheat (*Triticum durum*, variety Waha) and barley (*Hordeum vulgare*, variety Saida), in order to characterize the potential beneficial or harmful effects of the allelochemicals on these crops.

I. MATERIALS AND METHODS

I.1. Plant material

Untreated seeds of durum wheat variety "Waha", and barley variety "Saida" were selected to show allelopathic effect in white mustard (*Sinapis arvensis*). These seeds were brought from the Technical Institute of Agricultural Crops (ITGC) of Oued Smar, El-Harrach, Algeria. They were taken from the harvest of the 2017-2018 campaign, with a germination capacity of 99%. The two species have been washed with drinking water, then with distilled water three times. Afterwards, they were soaked for five minutes in a sodium hypochlorite solution at the concentration of 10% for disinfection. Finally, the seeds were washed three times with distilled water. The samples of the white mustard weed (*Sinapis arvensis*) were unearthed from the experimental station of biotechnologies department, then brought back in plastic bags to the research laboratory of Plant productions biotechnologies, faculty of natural and Life sciences, Blida 1 University, Algeria.

2.2. Crops germination

After disinfection of the seeds of two tested species, 10 seeds of each were placed on a filter paper in Petri dishes (9cm in diameter). Then volumes of extracts from the different parts (aerial and root), fresh or dry, were added in proportions of 0; 2.5; 5; 7.5 and 10 ml in each Petri dish, completing the final volume to 10 ml by adding distilled water. For this, five concentrations (0; 25; 50; 75 and 100%) were obtained and tested. In total, five tests were carried out. For each trial, five concentrations were tested according to a fully randomized experimental design with four replicates. Petri dishes were incubated in the dark in a cultivation chamber for 10 days at room temperature of 25 ° C.

2.3. Preparation of weed extracts by grinding

The harvest of *Sinapis arvensis* was carried out in the green state and in the bloom during February 2019. A separation of the leaf and root organs was made. Drying the two samples away from heat and light was carried out on a paper for 20 days to preserve the allelopathic power of the tested weed and to prevent oxidation of the plant. After drying, 75g of each part of the plant was mixed in 250 ml of distilled water, crushed for five minutes, and left for 30 minutes for filtration. As a final step, each mixture was filtered through a 0.15 mm sieve and then through Whatman filter paper [9].

2.4. Measurement and observations that made

The germinated seeds are counted daily when the 1 mm long radicle has pierced the integuments, the germination criterion retained in our experiment. Observations are carried out daily to record the number of germinated seeds. For each Petri dish, the percentage and the germination kinetics are two parameters carried

out for the germination phase and the average length and the fresh biomass of coleoptile and radicle are carried out to estimate the morphological parameters.

2.4.1. Germination kinetics

The germination kinetics is a germination curve, which describes the germination course of the seed lot that considered placed under precise conditions. It is most often representing the change in cumulative germination percentages as a function of time. This kinetics is established from the seed rates, that is to say the variation in germination rates as a function of time expressed in days under all the treatment conditions tested. The germination curves give a complete idea of the germination evolution of a seed lot placed under certain conditions [10].

2.4.2. Final germination rate (GR %)

Based on the total number of the sown seeds (N_s), we calculate the number of germinated seeds (N_g). Subsequently, the final seed germination rate (TG) is calculated according to the following relation:

$$TG (\%) = \frac{N_g}{N_s} \times 100$$

2.4.3. Inhibition rate (TI %)

The following relation [11] expresses the ability of a substance or preparation to inhibit seed germination:

$$TI (\%) = \frac{(N_s - N_g)}{N_s} \times 100$$

N_s : Number of sown seeds.

N_g : Number of germinated seeds.

2.4.4. Length of coleoptile and rootlet (cm)

The length of the coleoptile and rootlet expressed in (cm) are measured using Digimizer software (2005-2011 Med Calc. Software).

2.4.5. Fresh biomass of coleoptile and radicle (g)

The fresh biomass of the two organs (coleoptile and radicle) expressed in (g) is carried out using a precision balance.

2.5. Statistical data analysis

The data were analyzed using one-way analysis of variance (ANOVA) with XLSTAT 2019 software, version 2.2.59417. Mean values and standard errors (SE) were calculated from four replicates for all parameters using Excel 2013. Mean comparisons were performed using the least significant difference (LSD) test at 5%. A probability (P) value of 0.05 was considered statistically significant, while a P value below 0.05 was regarded as highly significant.

3. RESULTS AND DISCUSSION

3.1. Effect of aqueous extracts of *Sinapis arvensis* on germination

3.1.1. Germination kinetics

Figures 1 and 2 shows the evolution of seed germination of wheat and barley crops as a function of time for all of the studied concentrations 0, 25, 50, 75 and 100 %. The results showed that the curves of the germination rates of the treated seeds lie below those of the control curves and approach zero as the dose of the aqueous solution concentration increases. We noticed that the Waha variety evolved more quickly than the Saida variety whose applied extract is from the aerial or root part (Fig. 1 and 2).

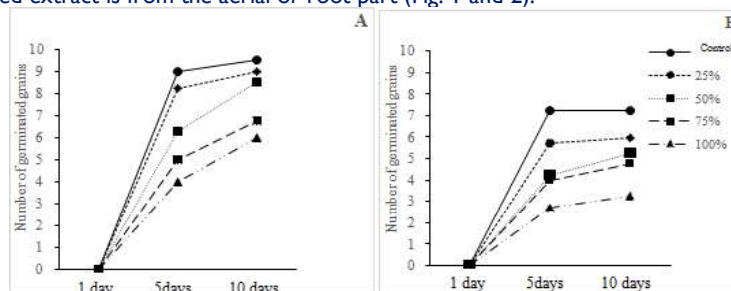


Fig.1. Germination kinetics of wheat seeds (A) and barley (B) during a period of 10 days by a function of the concentrations 0, 25, 50, 75 and 100% of the aqueous extract of *Sinapis arvensis* aerial part.

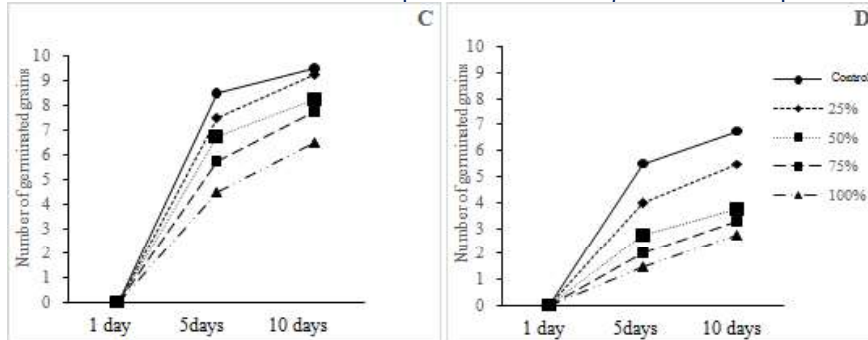


Fig.2. Germination kinetics of wheat seeds (A) and barley (B) during a period of 10 days by a function of the concentrations 0, 25, 50, 75 and 100% of the aqueous extract of *Sinapis arvensis* root part.

The germination curves allow distinguishing two phases:

- A first substantially linear phase, corresponding to a rapid increase in the germination rate which changes in proportion to time, at least for the control plants and the subjected plants to a solution at a concentration of 25%. For the 100% concentration, this phase is very short, which explains the reduced rate of germination due to the allelopathic inhibitory effect on germination.
- A second phase corresponding to a level representing the final percentage of germination and translating the germination capacity of each variety and for each concentration. It appears that this germinating capacity decreases for both studied varieties but with different degrees, depending on the species, the part used in the extraction (aerial or root) and the concentration of the applied solution.

3.1.2. Final germination rate (GR %)

Although it does not fully reflect the behavior of the two studied plants under their natural conditions, the germination rate, under controlled conditions, always gives a more or less precise idea of the studied varieties behavior.

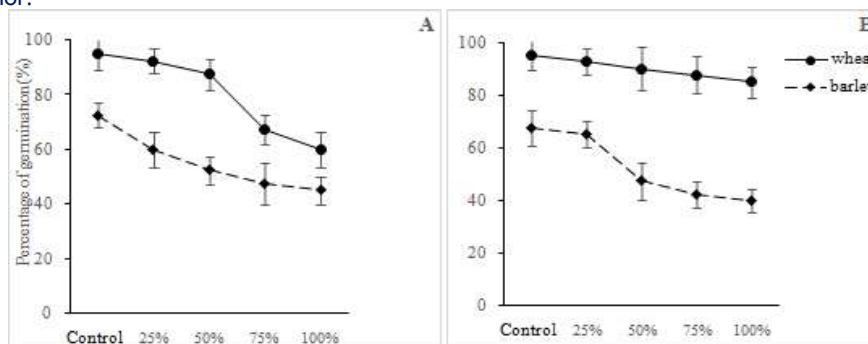


Fig. 3: Final germination rate (TG%) of wheat and barley seeds during a period of 10 days by a function of the concentration 0, 25, 50, 75 and 100% of the aqueous extract of the *Sinapis arvensis* aerial part (A) and root (B). Fig. 3 shows that, whatever the variety, the germination capacity of the seeds is reduced compared to the control and this for the five used treatments. Indeed, when the concentration of the aqueous solution of *S. Alba* in the leaf part is low (50% and 25%), no significant effect was recorded in the Waha variety compared to the control. However, when the concentration of this solution is pure or diluted to 75%, the germination rate showed a regression equivalent of 36.84% and 28.94% compared to the control respectively. In contrast, this variety showed no significant effect on the aqueous solution concentration of *S. Alba* root part compared to the control. In addition, all the tested concentrations exerted a germination rate, which did not exceed 10.52% relative to the control. On the other hand, the variety Saida showed a significantly remarkable sensitivity to the

increasing concentration of *S. Alba* aqueous solution and it showed a depressive effect on the germination rate of 37.92 and 40.74% in the pure concentration of the leaf and root part respectively compared to the control.

3.1.3. Final inhibition rate (TR %)

The data in Fig. 4, illustrating the effect of the aqueous solution concentrations of the aerial (Fig. 4. A) and the root part (Fig. 4. B) of *Sinapis arvensis* on the inhibition rate of germination expressed in %. The plant leaf or root extract, pure or diluted to 75%, has an exceptional ability to inhibit the germination of wheat seeds compared to barley seeds. For the lower concentrations (50% and 25%), the maximum inhibition rate recorded varies between 70.90% and 45.45% for barley seeds. Compared to the root extract, the maximum inhibition rate is 61.53%. For wheat seeds, the maximum inhibition rate recorded ranges from 150% to 50% for the plant-leaf extract. While it varies between 100% and 50% for the plant root extract. Generally, it is noted that the leaf extract has a more effective germination inhibiting capacity than that of the root extract.

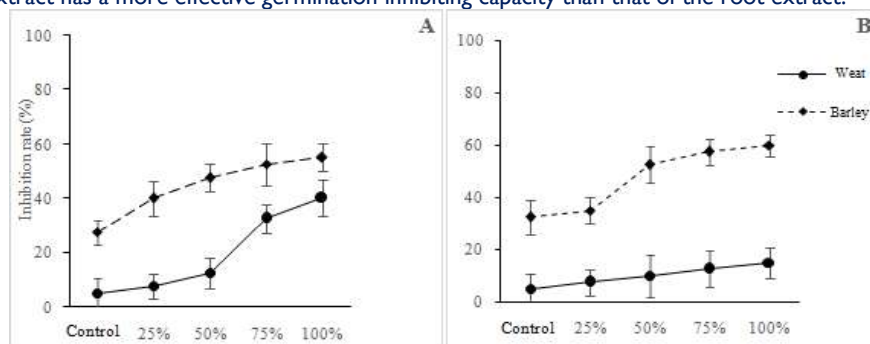


Fig. 4: Inhibition rate of wheat and barley seeds germination of during a period of 10 days by a function of the concentrations 0, 25, 50, 75 and 100% of the aqueous extract of *Sinapis arvensis* aerial (A) and root part (B).

3.2 Effect of *Sinapis arvensis* aqueous extracts on growth

3.2.1. Average coleoptile length (cm)

In view of Fig. 5 results, the allelopathic effect of the used extract concentration of *Sinapis arvensis* on seems obvious. A continual decrease in coleoptiles length of both cultures was revealed. It varies between 89.83% and 77.80% in the presence of pure extracts of leaf and root of wheat culture respectively, and between 82.34% and 38.86% for the culture of barley compared to the control. In 25% extract, coleoptile length was observed at 45.26% and 35.62% reduction in leaf extract and 52.04% and 22.20% in root extract for cultivation wheat and barley respectively compared to the control. The Percentage reduction increases by 16.94% and 6.16% of the reductions already recorded for the two cultures respectively at 50% leaf extract concentration and increases by 10.27% and 4.50% in root extract. Nevertheless, at an extract concentration of 75% the reductions were 70.02% and 57.36% in the leaf extract and 64.14% and 35.27% in the root extract respectively with respect to the control.

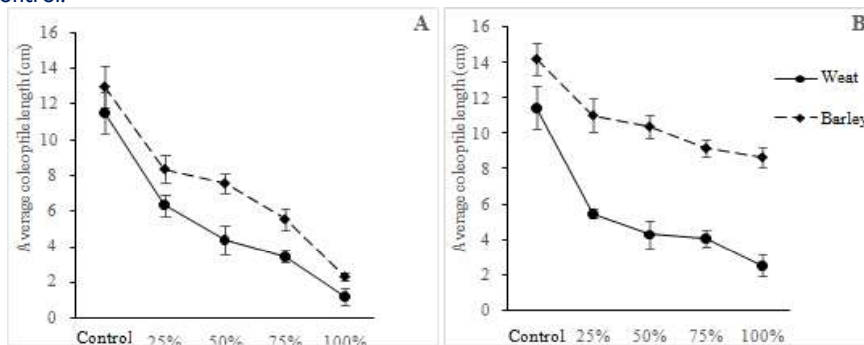


Fig. 5. Average coleoptile length (cm) of young wheat and barley seedlings by a function of concentrations 0, 25, 50, 75 and 100% of the *Sinapis arvensis* aqueous extract of the aerial part (A) and root part (B).

3.2.2. Average root length (cm)

According to the results shown in Fig. 6, the allelopathic effect of the aqueous leaf and root extract of *Sinapis arvensis* is certain. It depends on the concentration and the organ being tested.

The presence of pure extracts of *Sinapis arvensis* leaf and root exerts the strongest inhibition. They vary between 91.43% and 78.12% in the presence of foliar and root extracts of the wheat culture respectively, and between 70.87% and 48.55% for the barley culture compared to the control. In the extract of 25%, the length of the radicles was observed at 47.43% and 46.53% for the culture of reduction wheat in leaf extract while it did not exceed 8.98% and 8.74% for the culture of barley in the leaf and root extract respectively compared to the control. However, at a concentration that diluted to 75%, the mean length of the radicles showed a regression equivalent to 76.07% and 74.58% in the presence of the leaf and root extracts for the cultivation of wheat, respectively, and 33.66% and 34.98% in the presence of the leaf and root extracts for the cultivation of barley respectively.

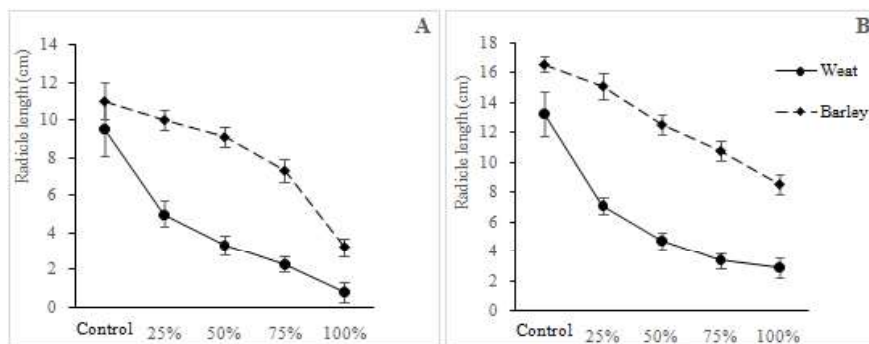


Fig. 6: Average radicle length (cm) of young wheat and barley seedlings by a function of the concentrations 0, 25, 50, 75 and 100% of the *Sinapis arvensis* aqueous extract of the aerial part (A) and root part (B).

3.2.3. Average fresh biomass of coleoptiles (g)

The data in Fig 7, illustrating the concentrations effect of the aqueous solution of *Sinapis arvensis* aerial (Fig. 7. A) and root (Fig. 7. B) part on the average fresh biomass of coleoptiles of young wheat seedlings and barley expressed in [g]. It is clear that the foliar and root organs of *Sinapis arvensis* have remarkable allelopathic effects on the fresh biomass of coleoptiles of wheat and barley, depending on the concentration of the tested aqueous solution. A continual decrease varies between 90% and 77.77% in the presence of the pure extracts of leaf and root for the wheat culture respectively, and between 60% and 61.53% for the culture and barley compared to the control. However, at a concentration of 75%, the average fresh biomass of coleoptiles showed a regression equivalent to 75% and 66.66% in the presence of foliar, root extracts for the wheat culture respectively, it varies between 20% and 46.15 % in the presence of leaf, and root extracts for barley cultivation respectively. In 25% extract, the average fresh biomass of coleoptiles was observed at 50% and 55.55% reduction in the leaf extract and 0% and 23.07% in the root extract for the cultivation of wheat and barley respectively compared to the control.

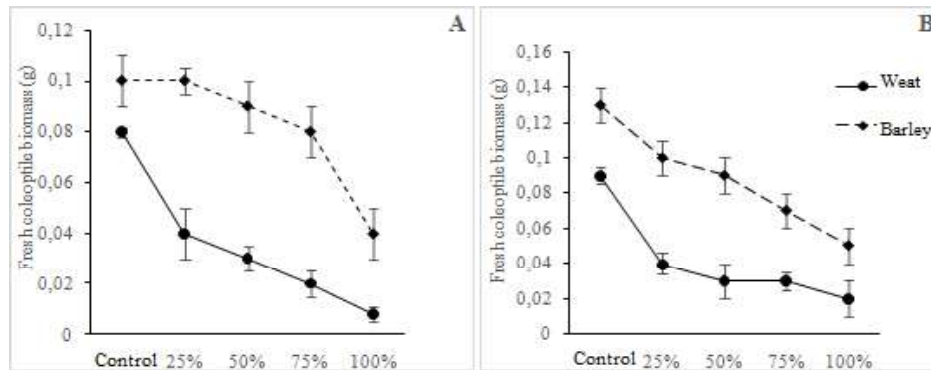


Fig. 7: Average fresh biomass of coleoptiles [g] of young wheat and barley seedlings by a function of the concentrations 0, 25, 50, 75 and 100% of the aqueous extract of the aerial part (A) and the root part (B).

3.2.4. Average fresh radicle biomass (g)

The data in fig. 8 shows the effect of the aqueous solution concentrations of the aerial (Fig. 7. A) and root (Fig. 7. B) parts of *Sinapis arvensis* on the average fresh biomass of young wheat seedlings radicles, and barley expressed in [g].

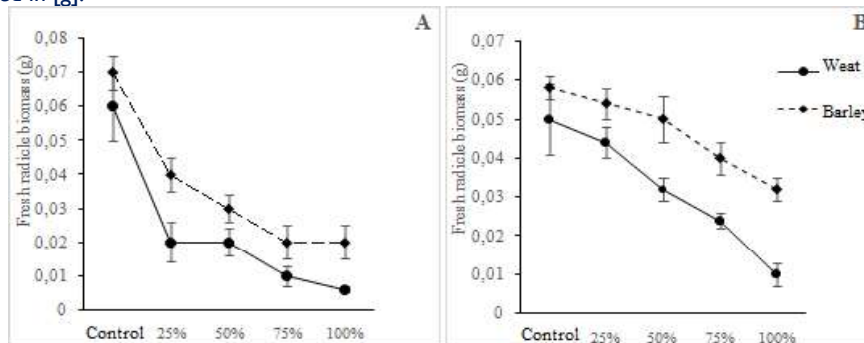


Fig. 8: Radicles average fresh biomass [g] of young wheat and barley seedlings by a function of the concentrations 0, 25, 50, 75 and 100% of the aqueous extract of the aerial part (A) and root part (B).

The presence of the pure extracts of *Sinapis arvensis* leaf and root exerts the strongest inhibition. They vary between 99% and 80% in the presence of foliar and root extracts for the wheat culture respectively, and between 71.42% and 44.82% for the barley culture compared to the control. However, at a concentration of 75 %, the average fresh biomass of the radicles showed a regression equivalent to 83.33% and 52% in the presence of leaf, root extracts for the wheat culture respectively, 71.42%, and 31.03% in the presence of leaf, and root extracts for barley culture respectively. In 50% concentration of the extract, the average fresh biomass of the radicles was observed at 66.66% and 52% for the wheat reduction culture in the leaf extract whereas it does not exceed 57, 14% and 13.79% for the culture of barley in the leaf and root extract respectively relative to the control.

4. Discussion

Weeds of the genus *Sinapis* (Brassicaceae) represent a major biotic constraint on cereal production in Algeria, particularly for strategic crops such as wheat and barley. Phytochemical studies of the Brassicaceae family highlight a high content of secondary metabolites, including glucosinolates, flavonoids, and sterols [12]. Allelochemicals have been identified in various plant organs and are known to significantly affect neighboring plants. In Brassicaceae, the primary allelopathic compounds are isothiocyanates, derived from the catabolism of glucosinolates in plant tissues incorporated into the soil. Understanding the complex mechanisms of allelopathy requires knowledge of precursor structures, diversity and quantity, plant matrices, cofactors (enzymatic or otherwise), and environmental conditions such as temperature and pH [13]. These compounds offer potential for developing non-synthetic alternatives for weed management.

Most studies report allelopathic effects of aqueous extracts, primarily inhibiting germination, biomass production, and root elongation [14, 15]. Our study showed that all aqueous treatments of *Sinapis arvensis* had a weaker effect on durum wheat germination compared to barley, although leaf extracts exhibited more pronounced allelopathic activity than root extracts, particularly at 75% and 100% concentrations. Lower concentrations did not significantly affect germination or early growth, though notable impacts on plant development were observed. Initial exposure to allelochemicals likely forces recipient plants to reallocate resources toward defense rather than growth, temporarily reducing overall growth rate.

Once allelochemical effects diminish, plants can readjust metabolic activity, explaining the absence of visible effects at harvest time. Water-soluble phenolic compounds in the extracts are likely responsible for reduced germination and biomass production, potentially by disrupting hormonal balance, protein synthesis, enzyme activity, photosynthesis, and respiration [18–20]. In particular, inhibition of germination may involve alterations in gibberellic acid activity, which regulates amylase synthesis during seed germination [20]. Phenolic compounds may also depress and delay germination by inhibiting respiration, affecting enzymes of the pentose phosphate pathway, DNA and RNA synthesis, ATP production, and Calvin cycle intermediates during early leaf greening [21]. Inhibition of DNA synthesis in primary meristems and roots, as well as slowed incorporation of amino acids for protein and nucleic acid synthesis, has been reported [22–24].

These compounds may additionally regulate plant hormone activity, including suppression of indole acetic acid (IAA) degradation. Our results confirm that both leaf and root organs of *S. arvensis* exert significant allelopathic effects on coleoptile and radicle elongation in wheat and barley. Growth inhibition likely arises from phytotoxic compounds released from the leaves and roots. These findings are consistent with previous reports showing a concentration-dependent inhibitory effect of plant extracts on germination and growth [25]. Alkaloids and flavonoids may inhibit key plant enzymes (e.g., ATPase) or disrupt processes such as phosphorylation, oxidative metabolism, membrane transport, and protein or lipid synthesis, leading to metabolic disturbances. For instance, cinnamic acid treatment in crabapple seeds reduced the activity of phosphofructokinase, glucose-6-phosphate dehydrogenase, and malate dehydrogenase, which are essential for glycolysis, the pentose phosphate pathway, and the tricarboxylic acid cycle, resulting in reduced respiration, growth retardation, and impaired nutrient uptake [25, 26].

In our study, extracts from leaves and roots of *S. arvensis* caused more pronounced morphological disturbances in wheat seedlings than in barley, significantly reducing radicle and coleoptile length as well as biomass. This aligns with previous findings showing that higher extract concentrations inhibit primary and lateral root development, decrease root hair length and density, impair cell division at root tips, and increase chromosomal aberrations and micronucleus formation [27]. Decreased fresh biomass accumulation may also result from disrupted cell division and impaired photosynthetic activity [2]. The inhibitory effects of water-soluble phenolic compounds on germination and growth have been widely documented [18, 28, 29].

5. CONCLUSION

This study demonstrates the significant allelopathic potential of *Sinapis arvensis* on key cereal crops such as durum wheat (*Triticum durum*) and barley (*Hordeum vulgare*). Laboratory bioassays confirmed that water-soluble allelochemicals are released from both leaves and roots, inhibiting germination, reducing radicle and coleoptile elongation, and decreasing seedling biomass. Leaf extracts generally exerted stronger effects than root extracts, and higher concentrations caused more pronounced growth inhibition. These effects are likely mediated by phenolic compounds, glucosinolate-derived isothiocyanates, flavonoids, and other secondary metabolites that disrupt enzymatic activity, hormonal balance, protein synthesis, and metabolic pathways essential for early plant growth. The findings suggest that *S. arvensis* has the potential to act as a natural bioherbicide, offering an alternative to synthetic chemicals for sustainable weed management in wheat and barley cultivation. Moreover, its residues may contribute positively as an organic fertilizer, enhancing soil fertility and crop productivity. However, further research is required to identify and characterize the specific allelochemicals involved and to validate their biological activity under field conditions within their natural habitat. A deeper understanding of the allelopathic interactions of *S. arvensis* could provide innovative strategies for managing spontaneous flora in cultivated plots, reducing dependence on synthetic herbicides while promoting environmentally friendly and sustainable agricultural practices. Overall, this study highlights the dual potential of *S. arvensis* as both a

bioherbicide and a natural soil amendment, offering promising applications for integrated crop management and sustainable cereal production in regions such as Algeria.

Références

- [1] A. Djermoun, "La production céréalière en Algérie : les principales caractéristiques," vol. 45, p. 53, 2009.
- [2] C. Hachani, M. Abassi, C. Lazhar, M. S. Lamhamedi, and Z. Béjaoui, "Allelopathic effects of leachates of *Casuarina glauca* Sieb. ex Spreng. and *Populus nigra* L. on germination and seedling growth of *Triticum durum* Desf. under laboratory conditions," *Agrofor. Syst.*, vol. 93, no. 5, pp. 1973–1983, 2019, doi: 10.1007/s10457-018-0298-3.
- [3] D. N. M. G and D. Nicolas, "Phénomènes d' allélopathie : premières observations au champ Journées techniques nationales fruits & légumes et viticulture biologiques : Beaune," vol. 34, pp. 383–387, 1998.
- [4] S. Jose, "Agroforestry for ecosystem services and environmental benefits : An overview," *Agrofor. Syst.*, vol. 76, no. 1, pp. 1–10, 2009, doi: 10.1007/s10457-009-9229-7.
- [5] F. Cheng and Z. Cheng, "Research progress on the use of plant allelopathy in agriculture and the physiological and ecological mechanisms of allelopathy," *Front. Plant Sci.*, vol. 6, no. NOVEMBER, pp. 1–16, 2015, doi: 10.3389/fpls.2015.01020.
- [6] M. K. Amb and A. S. Ahluwalia, "Allelopathy : Potential Role to Achieve New Milestones in Rice Cultivation," *Rice Sci.*, vol. 23, no. 4, pp. 165–183, 2016, doi: 10.1016/j.rsci.2016.06.001.
- [7] C. R. Das, N. K. Mondal, P. Aditya, J. K. Datta, A. Banerjee, and K. Das, "Allelopathic Potentialities of Leachates of Leaf Litter of Some Selected Tree Species on Gram Seeds under Laboratory Conditions," *Asian J. Exp. Biol. Sci.*, vol. 3, no. 1, pp. 59–65, 2012.
- [8] M. Scognamiglio, "Identification of Potential Allelochemicals From Donor Plants and Their Synergistic Effects on the Metabolome of *Aegilops geniculata*," *Front. Plant Sci.*, vol. 11, no. August, 2020, doi: 10.3389/fpls.2020.01046.
- [9] S. Ben-ghabrit and M. Bouhache, "Effets allélopathiques d'une adventice envahissante (*Verbesina encelioides* Cav. Benth & Hook) sur la germination et la croissance du blé dur. December, 2017.
- [10] D. Come, " Les Obstacles à la Germination, 1970," *Bull. Mens. la Société linnéenne Lyon*, vol. 40, no. 7, p. p.108, 1971.
- [11] F. Talhi, N. Gherraf, and A. Zellagui, "Allelopathic effect of the aqueous extract of *Lantana camara* L . on the germination and development of four vegetable species," vol. 18, pp. 116–121, 2020.
- [12] A. Berreghioua, "Investigation phytochimique sur des extraits bioactifs de deux brassicaceae medicinales du sud algerien : *Moricandia arvensis* et *Zilla macroptera*," pp. 2015–2016, 2016.
- [13] R. Reau et al., "Effets allélopathiques des Brassicacées via leurs actions sur les agents pathogènes telluriques et les mycorhizes : analyse bibliographique. Partie II," *Oléagineux, Corps gras, Lipides*, vol. 12, no. 4, pp. 314–319, 2005, doi: 10.1051/ocl.2005.0314.
- [14] C. G. Puig, M. J. Reigosa, P. Valentão, P. B. Andrade, and N. Pedrol, "Unravelling the bioherbicide potential of *Eucalyptus globulus* Labill: Biochemistry and effects of its aqueous extract," *PLoS One*, vol. 13, no. 2, pp. 1–16, 2018, doi: 10.1371/journal.pone.0192872.
- [15] V. Rueda-Ayala et al., "Allelopathic properties of *Calliandra haematocephala* Hassk. extracts and fractions as an alternative for weed management in quinoa and rice crops," *Acta Physiol. Plant.*, vol. 42, no. 4, pp. 1–14, 2020, doi: 10.1007/s11738-020-03041-z.
- [16] A. Ghatak, P. Chaturvedi, and W. Weckwerth, "Metabolomics in plant stress physiology," *Adv. Biochem. Eng. Biotechnol.*, vol. 164, pp. 187–236, 2018, doi: 10.1007/10_2017_55.
- [17] B. D'Ambrosia, "Plant bioassay to assess the effects of allelochemicals on the metabolome of the target species *Aegilops geniculata* by an NMR-based approach," *Phytochemistry*, vol. 93, pp. 27–40, 2013, doi: 10.1016/j.phytochem.2013.03.016.
- [18] A. Zohaib, T. Tabassum, S. A. Anjum, T. Abbas, and U. Nazir, "Efeito alelopático de algumas plantas daninhas do trigo associadas na germinabilidade e produção de biomassa de plântulas do trigo," *Planta Daninha*, vol. 35, 2017, doi: 10.1590/S0100-83582017350100089.
- [19] A. Zohaib, T. Abbas, and T. Tabassum, "Weeds Cause Losses in Field Crops through Allelopathy," *Not. Sci. Biol.*, vol. 8, no. 1, 2016, doi: 10.15835/nsb.8.1.9752.
- [20] N. Jafri, M. Mazid, and F. Mohammad, "Responses of seed priming with gibberellic acid on yield and oil quality of sunflower (*Helianthus annuus* L.)," *Indian J. Agric. Res.*, vol. 49, no. 3, pp. 235–240, 2015, doi: 10.5958/0976-058X.2015.00036.0.
- [21] D. Pergularia, "a Queux De P *Ergularia Tomentosa* L .," *Leban. Sci. J.*, vol. 17, no. June, p. 26, 2016, doi: 10.22453/LSJ-017.1.025035.
- [22] A. Mishra, "Allelopathic properties of *Lantana camara*," *Int. Res. J. Basic Clin. Stud.*, vol. 3, no. 1, pp. 13–28, 2015, doi: 10.14303/irjbs.2014.048.
- [23] J. John and S. Sarada, "Role of phenolics in allelopathic interactions," *Allelopath. J.*, vol. 2, no. July, pp. 215–230, 2012.
- [24] A. Ladhari, B. Gaaliche, A. Zarrelli, M. Ghannem, and M. Ben Mimoun, "Allelopathic potential and phenolic allelochemicals discrepancies in *Ficus carica* L. cultivars," *South African J. Bot.*, vol. 130, pp. 30–44, 2020, doi: 10.1016/j.sajb.2019.11.026.
- [25] D. Soltys et al., "Phytotoxic cyanamide affects maize (*Zea mays*) root growth and root tip function : From structure to gene expression," *J. Plant Physiol.*, vol. 171, no. 8, pp. 565–575, 2014, doi: 10.1016/j.jplph.2014.01.004.
- [26] X. Bin Gao, "Effects of cinnamon acid on respiratory rate and its related enzymes activity in roots of seedlings of *malus hupehensis* rehd.," *Agric. Sci. China*, vol. 9, no. 6, pp. 833–839, 2010, doi: 10.1016/S1671-2927(09)60161-9.
- [27] D. Sarma, P. Basumatary, and B. K. Datta, " Allelopathic impact of *Melastoma malabathricum* L. on the seed germination and seedling growth of three agricultural crops" *J. Indian Bot. Soc.*, vol. 98, no. 3and4, p. 183, 2019, doi: 10.5958/2455-7218.2019.00021.4.
- [28] A. Gulzar and M. B. Siddiqui, "Allelopathic effect of *Calotropis procera* (Ait.) R. Br. on growth and antioxidant activity of *Brassica oleracea* var. botrytis," *J. Saudi Soc. Agric. Sci.*, vol. 16, no. 4, pp. 375–382, 2017, doi: 10.1016/j.jssas.2015.12.003.
- [29] A. Tanveer, A. Khaliq, H. H. Ali, G. Mahajan, and B. S. Chauhan, "Interference and management of parthenium : The world's most important invasive weed," *Crop Prot.*, vol. 68, pp. 49–59, 2015, doi: 10.1016/j.cropro.2014.11.005.