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Seedling growth response of two durum wheat genotypes to the allelopathic activity of *Avena sterilis* L.

Original Article

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Abstract:

This study evaluated the allelopathic effects of aqueous extracts of wild oat (*Avena sterilis* L.) on seedling growth of two durum wheat types: a landrace (MBB) and an introduced genotype (Waha). The experiment was conducted under controlled laboratory conditions using grain and envelope extracts at concentrations of 0%, 25%, 50%, 75%, and 100%. Results showed that genotype significantly affected most growth parameters, except root length, while extract type influenced all parameters. Concentration significantly affected only root and leaf lengths. Significant interactions between genotype and concentration, and extract and concentration, were observed. Grain extracts stimulated root number in MBB, whereas envelope extracts inhibited coleoptile length in Waha. Leaf length decreased under higher grain extract concentrations. These findings demonstrate genotype-specific allelopathic responses under laboratory conditions and provide a scientific basis for future field investigations and sustainable agronomic management strategies under diverse environmental conditions.

Key words:
Germination parameters, aqueous extract, grain and envelope extracts, inhibition, genotypic variation

Apstrakt:

Odgovor rasta klijanaca dva genotipa durum pšenice na alelopatsku aktivnost divljeg ovsa (*Avena sterilis* L.)

Ova studija je procenjivala alelopatske efekte vodenih ekstrakata divljeg ovsa (*Avena sterilis* L.) na rast klijanaca dva tipa durum pšenice: domaće sorte (MBB) i introdukovanog genotipa (Waha). Eksperiment je sproveden u kontrolisanim laboratorijskim uslovima korišćenjem ekstrakata zrna i ovojnice u koncentracijama od 0%, 25%, 50%, 75% i 100%. Rezultati su pokazali da je genotip značajno uticao na većinu parametara rasta, osim na dužinu korena, dok je tip ekstrakta uticao na sve parametre. Koncentracija je značajno uticala samo na dužinu korena i listova. Uočene su značajne interakcije između genotipa i koncentracije, kao i između tipa ekstrakta i koncentracije. Ekstrakti zrna su stimulisali broj korenova kod MBB, dok su ekstrakti ovojnice inhibirali dužinu koleoptile kod Waha genotipa. Dužina lista se smanjivala pri višim koncentracijama ekstrakta zrna. Ovi nalazi ukazuju na genotipski specifične alelopatske odgovore u laboratorijskim uslovima i pružaju naučnu osnovu za buduća terenska istraživanja i održive agronomske strategije upravljanja u različitim uslovima životne sredine.

Ključne reči:
Parametri klijanja, vodeni ekstrakt, ekstrakti zrna i ovojnice, inhibicija, genotipska varijabilnost

Introduction

In Algerian farming systems, wheat cropping is mainly practiced under rainfed conditions. National production covers only 30% to 35% of the population's needs (Haddad et al., 2016).

This low production is primarily constrained by multiple factors, including abiotic stresses such as irregular rainfall and inappropriate agricultural practices, as well as biotic constraints, mainly diseases, limited genetic potential, pests, and weeds (Benabderrazik & Rastoin, 2014). Cereal crops are highly sensitive to weed competition, which can markedly reduce yield. Among these weeds, wild oat (*Avena sterilis* L.) poses the main threat, dominating wheat-growing areas in many localities in Algeria. *Avena sterilis* emerges at the same time as wheat and exhibits a morphology and physiology similar to that of cultivated plants, while having a high demand for water and nutrients (Dhima & Eleftherohorinos,

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2001). This similarity gives it a competitive advantage, promoting its development and making its control difficult. Its long emergence period and its resemblances to crops provide it with excellent opportunities to become an aggressive invader. Indeed, allelopathy is one of the mechanisms that enhances this competitiveness.

Allelopathy refers to a direct or indirect biochemical interaction between crops and weeds, which may exert either beneficial or detrimental effects. It occurs through the release of chemical compounds into the environment, thereby affecting the growth and development of surrounding plants. This phenomenon may play a crucial role in biological invasion processes (Sangeetha & Baskar, 2015).

Although leaves are commonly used in allelopathic studies, other plant organs such as roots, stems, flowers, pollen, and seeds also constitute important sources of allelochemicals produced throughout the plant life cycle (Souza Filho et al., 2011). In oats, the levels of these compounds, especially phenolics and antioxidants, are elevated during grain development (Alfieri & Redaelli, 2015). Therefore, seeds were chosen in this study as a representative source of allelopathic activity.

The majority of previous research on allelopathy has focused on *Avena fatua* L., with limited attention to *A. sterilis* and even fewer studies targeting its seeds or glumes. However, these structures are known to harbor water-soluble allelochemicals that can be readily leached into the soil by rainfall or irrigation (Mubeen et al., 2011). Consequently, their potential role in crop–weed interactions remains underexplored. This study seeks to fill this gap by assessing the allelopathic effects of aqueous extracts from *A. sterilis* seeds and glumes on the germination and early growth of durum wheat seedlings. Specifically, we analyzed root number (RN), root length (RL), coleoptile length (CL), and leaf length (LL) under varying extract concentrations to disentangle organ-specific sensitivity and extract-dependent effects. This approach provides novel evidence of concentration-dependent, hormetic, and organ-specific responses, thereby refining the current understanding of allelopathic interactions in Mediterranean wheat systems.

Materials and methods

Plant material and experimental process

The plant material includes the grains and envelopes (glumes and lemmas) of *Avena sterilis*, used as a source of allelopathic compounds, and two durum wheat varieties, Mohammed Ben Bachir (MBB) as a landrace, and Waha as an introduced genotype. Seeds of both durum wheat varieties were obtained from the experimental station of the Technical Institute of Field Crops (ITGC), Sétif, Algeria. The seeds were selected based on uniform size, health, and absence of visible damage to ensure experimental consistency. The choice of (MBB) as a landrace is based on its excellent adaptation to local cropping conditions. It is a winter variety, derived from a local collection dating back to 1935, which is distinguished by a more pronounced vernalization and photoperiod requirements. It also exhibits a taller straw height (+80 cm) and a later heading (+10 days) compared to other durum wheat introduced genotypes, characteristics that allow it to survive spring frosts (Bouzerzour et al., 1995). Meanwhile, the introduced genotype (Waha) is an alternative spring-type, characterized by early heading. It is a semi-dwarf variety. It exhibits medium tillering and moderate tolerance to rusts. It has a medium thousand kernel weight and a fairly good semolina quality. It is better suited to arid regions, and offers good productivity (ITCG-CNCC 2006). The plant material of *Avena sterilis* was collected at the physiological maturity stage from a cereal field located at the experimental site of Ferhat Abbas Sétif 1 University. This stage was selected because it is associated with the highest allelochemical accumulation and reflects the composition of post-harvest plant residues. The collected wild oat grains were hulled to separate the husks (Envelopes) from the grains, keeping both parts. The seeds of wild oat were separated from the husks, and each part was air-dried in the dark at room temperature for five weeks. After drying, the plant material was ground using an electric grinder and subsequently sieved through a 0.75 mm mesh to obtain a fine powder. For the maceration extraction, we followed the protocol described by Rsaissi et al. (2013), in which 25 g of plant powder from each seed and hull fraction were immersed in 250 ml of distilled water at room temperature for 24 hours. The extract obtained was filtered through filter paper, centrifuged, and subsequently stored at 4 °C until further use. Four concentrations of extract from each part of the seeds and hulls of wild oats were prepared: (25%, 50%, 75%, 100%) and a control, consisting of distilled water (0%) (**Tab. 1**). Before sowing, the wheat seeds were disinfected in bleach for 5 minutes, followed by three successive rinses with distilled water. Four seeds of each wheat variety were sown in Petri dishes containing filter paper moistened with 5 ml of the extract from each part at different concentrations. Each treatment was replicated three times. The Petri dishes were incubated at 24 °C for 10 days, during which RN, RL, CL, and LL were measured.

Statistical Analyses

On the sixth day after sowing and the complete initiation of germination, all samples were photographed using a high-resolution digital camera. The obtained images were then analyzed to measure the lengths of the primary roots, coleoptiles, and first leaves using the ImageJ software. ImageJ processing enabled precise measurement of morphological dimensions (RN: root number; RL: root length; CL: coleoptile length; LL: leaf length) from photographs. For the statistical analysis, RStudio and JMP software were used. Analysis of variance (ANOVA) and correlations were used to simultaneously examine the effects of factors and their interactions, as well as the associations among growth parameters. Mean comparisons were performed using the HSD Tukey test. Also, a Principal component analysis (PCA) was performed to synthesize the relationships between quantitative variables and factors. The adopted levels of statistical significance are set at 5% (p<0.05) and 1% (p<0.01) for highly significant effects.

Table 1. Dilution rate of the stock extract and preparation of the concentrations

Concentration %	Control **0%**	**25%**	**50%**	**75%**	**100%**
Extract stock volume	0 ml	5 ml	10 ml	15 ml	20 ml
Distilled water volume	20 ml	15 ml	10 ml	5 ml	0 ml
Solution total volume	20 ml	20 ml	20 ml	20 ml	20 ml

Results

The results of the study reveal different physiological responses of the two wheat genotypes subjected different concentrations of two extracts. The landrace generally showed better performance (No inhibition) for RN (4.46 roots) and CL (6.00 cm), while the introduced genotype exhibited a higher LL (1.96 cm) (**Tab. 2**). The grain extract showed a repressive effect on RL (4.37 cm), CL (4.88 cm), and LL (1.23 cm). Whereas, RN was positively influenced by the application of the extract, with an average of 4.46, thus surpassing the control (4.00). The Envelope extract showed no significant effects on CL, RL, RN, or LL. The analysis of different concentrations highlighted RN stability regardless of the applied dose, while RL and LL progressively decreased with increasing concentration, suggesting an inhibitory effect at high doses. The means followed by the same superscript letters ($^{a, b, c}$) in each column indicate the absence of a significant difference between factors at the 5% threshold according to the Tukey post-hoc test, while different superscript letters reveal statistically significant differences.

Treatment with the aqueous extract of the envelopes

The results of the envelope extract showed an inhibitory effect on landrace growth across all parameters, particularly LL, which recorded the lowest length (0.64 cm) at the 100% concentration. The highest LL value (2.62 cm) was recorded at the 25% concentration. A higher RL (7.99) was recorded with the introduced genotype at the 50% concentration (**Fig. 1**). Generally, the RN results differ significantly between genotypes and concentrations. However, the CL values are remarkably different, with the landrace results higher across all concentrations than those for the introduced genotype. Indeed, the maximum CL value (6.73 cm) is recorded in landrace under the 75% concentration. The minimum CL value (3.70 cm) is observed for the introduced genotype at the 25% concentration.

Table 2. Marginal means of growth parameters of two durum wheat genotypes grown in the presence of the two different extracts

Factors	Modality	RN	RL	CL	LL
Genotype	Landrace genotype	4.46^{a}	5.39^{a}	6.00^{a}	1.36^{b}
	Introduced genotype	4.13^{b}	5.56^{a}	4.08^{b}	1.96^{a}
Extract	Envelope	4.13^{b}	6.52^{a}	5.17^{a}	2.08^{a}
	Grain	4.46^{a}	4.37^{b}	4.88^{b}	1.23^{b}
Concentration	0.00%	4.00^{a}	6.54^{a}	5.08^{a}	2.18^{a}
	25.00%	4.26^{a}	5.16^{b}	4.91^{a}	2.17^{a}
	50.00%	4.44^{a}	5.61^{b}	5.14^{a}	1.69^{ab}
	75.00%	4.31^{a}	5.41^{b}	5.02^{a}	1.37b^{c}
	100.00%	4.40^{a}	4.73^{b}	4.99^{a}	0.93^{c}

RN: Number of roots, **RL**: Root Length, **CL**: Coleoptile Length, **LL**: Leaf Length

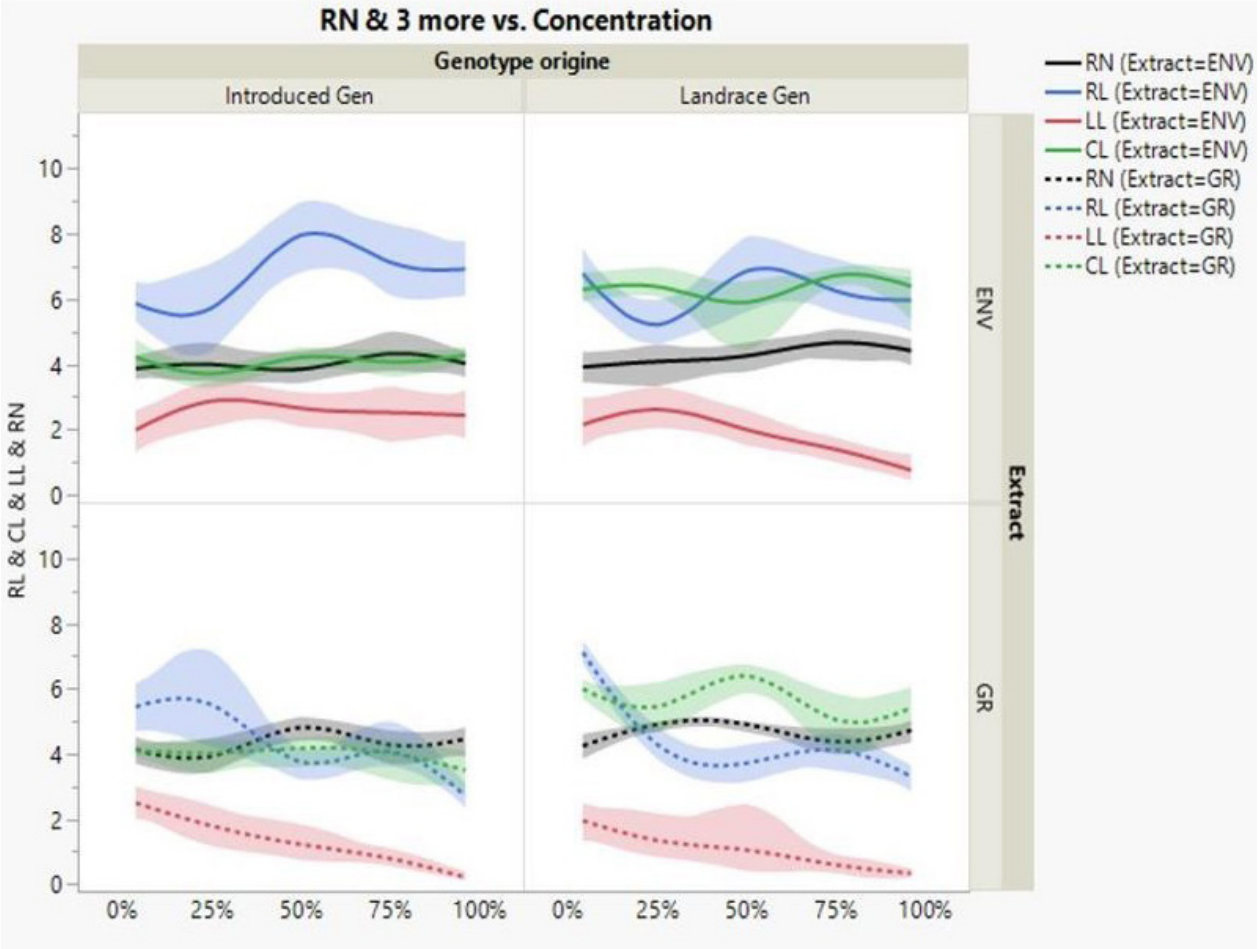


Fig. 1. Evolution of growth parameters at .95 CI, based on the extract, genotypes, and concentrations

Treatments with grain extract

The results of the treatment with the grain extract showed an inhibitory effect, with increasing dose across all measured parameters. The results for the landrace treated with the grain extract showed that the highest CL value (6.44) was observed at the 50% concentration. The lowest CL value (3.38 cm) was recorded for the introduced genotype at 100% concentration. Regarding LL and RN, these two parameters showed similar trends across both wheat genotypes, with the maximum LL value (2.62 cm) observed in the introduced genotype under the control and the minimum LL value (0.09 cm) under the 100% concentration. The differences in RN values were insignificant between varieties and across concentrations. While the effect of concentration is significant for RL, where the maximum RL (7.75 cm) was noted with the landrace control, while the minimum RL value (2.31 cm) was obtained with the introduced genotype under the 100% concentration (**Fig. 1**).

Study of correlations

Study of correlations under the effect of the envelope extract

Tab. 3 presents the correlations between the four growth variables, revealing two significant correlations at the 0.01 level: a positive correlation between CL and RN (r = 0.32) and a strong negative correlation between RN and RL (r = -0.414) (**Tab. 3**). This suggests that the coleoptile length is associated with an increased number of roots, while a high number of roots tends to coexist with shorter roots, indicating a possible physiological trade-off.

Study of correlations under the effect of grain extract

A strong positive correlation between CL and RN (r=+0.38, p<0.01) and between CL and RL (r=+0.35, p<0.01), as well as another positive correlation was observed between LL and LL (r=+0.42, p<0.01). Also, a negative correlation (r=-0.27, p<0.05) between RN and RL.

Table 3. Correlation coefficients between growth parameters treated with the envelope extract (above the diagonal) and with the grain extract (below the diagonal).

		CL	LL	RN	RL
CL	Pearson's r	**1**	-0.14	**0.32*****	0.14
	n	116	114	115	115
LL	Pearson's r	-0.01	**1**	0.18	0.15
	n	105	105	113	113
RN	Pearson's r	**0.38*****	0.02	**1**	**-0.41*****
	n	107	104	107	115
RL	Pearson's r	**0.35*****	**0 .42*****	**-0.27****	**1**
	n	107	104	107	107

RN: number of roots, **RL**: root length, **CL**: coleoptile length, **LL**: leaf length, *, **, *** and **n.s**: significance at p<0.05, 0.01, 0.001 and non-significant, respectively

Study of the effect of factors on growth parameters

The analysis of variance revealed differential effects of the studied factors on the growth parameters. The genotype factor exerted a highly significant influence on CL, LL, and RN. The concentration factor also showed a highly significant impact (p<0.001) on RL and LL. However, the extract factor showed significant effects on all parameters, as indicated by the ANOVA results in **Tab. 4**.

Study of Interactions

The analysis of interactions between factors reveals differentiated effects on growth parameters. The interaction Genotype*Extract was absent for the four variables. On the other hand, the interaction Genotype *Concentration showed a highly significant effect (p<0.001) on RL, indicating that RL response to different concentrations varies across varieties. The interaction Extract*Concentration had a significant influence at 5% on RN, a very highly significant effect (p<0.001) on RL, and a significant effect at 1% on LL. These results highlight that RL appears to be the parameter most sensitive to factor combinations, while CL remains insensitive to all interactions, as shown in **Tab. 5**.

The envelope extract had a stimulating effect on leaf development at low concentrations, increasing from 0% to 25%, where the average length went from 1.85 cm to 2.73 cm. Conversely, the grain extract showed an inhibitory effect, with a progressive reduction in LL values from 2.35 cm to 1.56 cm for the same concentrations (0% and 25%). However, on the RL, the envelope extract induced a marked stimulating effect, namely at the 50% concentration, where it increased from 5.43 cm at the 25% concentration to 7.65 cm at the 50% concentration. On the other hand, the grain extract exerted an inhibitory effect, reducing RL from 4.89 cm at 25% to 3.77 cm at 50%. This trend reversed between the concentrations of 50% and 75%, where the envelope extract exhibited

Table 4. Effect of the studied factors on the growth parameters

		Mean square			
Source of variation	**ddf**	**RN**	**RL**	**CL**	**LL**
Genotype	1	5.16*	0.70	208.19***	14.18**
Concentration	4	1.68	23.67***	0.91	12.86***
Extract	1	6.20**	254.19***	5.76*	42.67***

ddf: degrees of freedom, **RN**: number of roots, **RL**: root length, **CL**: coleoptile length, **LL**: leaf length, *, **, *** and **n.s**: significance at p<0.05, 0.01, 0.001 and non-significant respectively

Table 5. Interaction between factors based on growth parameters

		Mean square			
Source of variation	**ddf**	**RN**	**RL**	**CL**	**LL**
Genotype*Extract	1	0.31	10.03	0.57	4.26
Genotype *Concentration	4	0.94	13.21***	0.36	0.46
Extract*Concentration	4	2.44*	27.23***	2.18	5.17**

ddf: degrees of freedom, **RN**: number of roots, **RL**: root length, **CL**: coleoptile length, **LL**: leaf length, *, **, *** and **n.s**: significance at p<0.05, 0.01, 0.001 and non-significant, respectively

an inhibitory effect on RL, while the grain extract showed a slightly stimulating effect when moving from the 50% to 75% concentration. The landrace showed sensitivity at the 25% concentration, with a significantly lower minimum RL (4.71 cm) than the control (7.60 cm). However, the transition from 25% to 50% concentration showed a stimulating effect on RL in the landrace, whereas RL seemed less affected by the interaction Genotype*Concentration.

Explanatory analysis of growth parameters according to genotype and envelope factors

Both PCA biplots reveal distinct patterns in variable contributions and group separations. The PCA model explains 69.99% of the total variance. As shown in **Fig. 2**, RL and RN dominate PC1 (37.8% of variance), strongly differentiating the extract groups (ENV and GR), exhibiting high correlation and moderate influence on PC2. The non-overlapping ellipsoids confirm clear group separation driven primarily by PC1. In contrast, the second figure (MBB vs. Waha) shows that CL and RN jointly influence PC2 (32.1% of variance), indicating a multidimensional structure. The overlapping ellipsoids suggest a weaker distinction between groups. Particularly, LL has a low contribution across both PC1 and PC2, highlighting its weak discriminative power. The suboptimal variance explained by PC1 (37.8% < 50%) implies significant information in secondary components (Jolliffe, 2002), and the biplot geometry aligns with Gabriel's (1971) interpretation, where variable angles denote correlations and axis projections indicate contributions.

Discussion

The present study demonstrated that the growth of durum wheat seedlings was markedly inhibited by aqueous extracts of *Avena sterilis*, which are likely to be rich in allelochemical compounds. However, this inhibitory effect was not uniform, varying with extract concentration, wheat genotype, and plant organ. A detailed analysis revealed that the roots, coleoptiles, and shoots differed in their sensitivity to allelopathic stress, and that the two types of extracts (seed versus glume) exerted distinct, and sometimes contrasting, effects. Rather than limiting the findings to a generalized inhibitory action, our results disentangle the organ-specific and extract-specific responses, thereby providing a more nuanced understanding of how wild oat allelochemicals interfere with wheat early growth.

The results highlight the strong inhibitory effect of *A. sterilis* extracts on root growth, confirming the root system as the primary target of allelopathic stress. Root length (RL) of the durum landrace was reduced at all grain extract concentrations, with the shortest RL observed at 25% envelope extract. This inhibitory pattern is consistent with previous reports showing that aqueous extracts of *Avena fatua* L. and *Avena sterilis* L. markedly suppress RL and wheat growth at higher concentrations (Ahmad et al., 2014; Mali et al., 2021; Melakhessou, 2020).

Roots are particularly sensitive due to their direct exposure to allelochemicals and rapid cell division, making RL a reliable indicator of allelopathic activity (Chon et al., 2000; Atoum et al., 2006; Ben Ghabrit et al., 2017; Hussain et al., 2021).

Such root-specific inhibition has also been

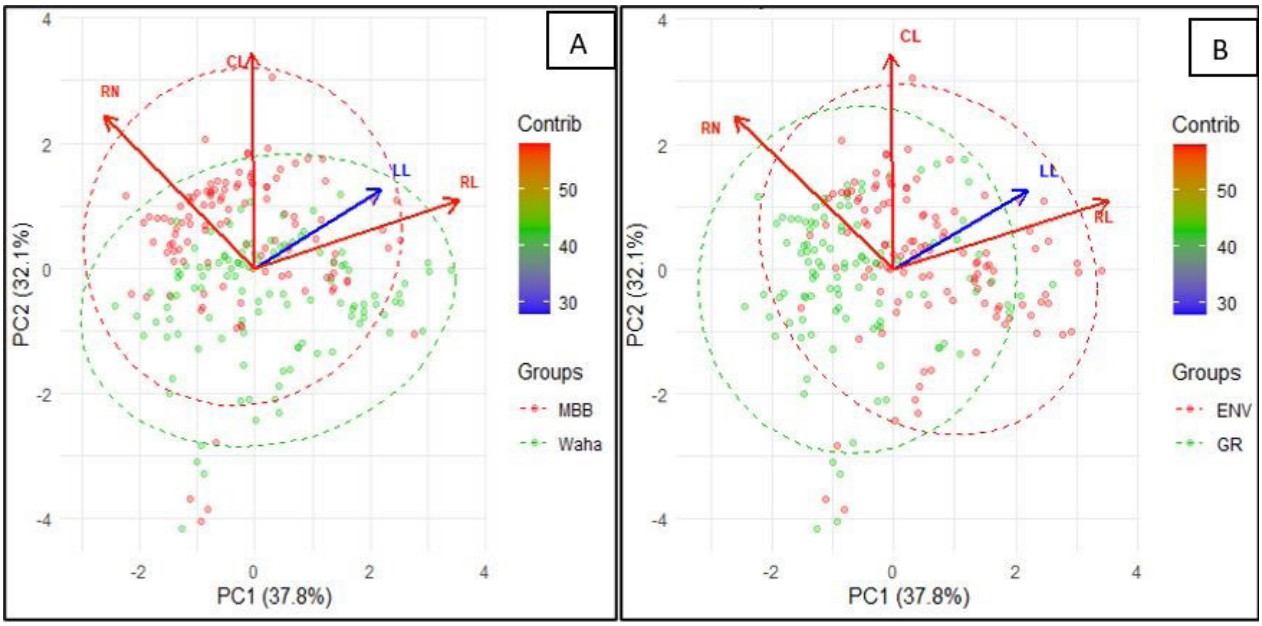


Fig. 2. PCA Biplot: ENV vs. GR (**A**) and "PCA Biplot: MBB vs. Waha (**B**) with Variable Loadings

documented in other cereals and weeds exposed to phenolic-rich extracts (Ruan et al., 2011), often linked to compounds like benzoic acid and juglone that disrupt auxin signaling and root elongation (Zhang et al., 2018).

The present study showed that low concentrations (25–50%) of aqueous *Avena sterilis* grain extract significantly stimulated the root number (RN) of landrace durum wheat. This aligns with the concentration-dependent nature of allelopathy, in which low doses promote growth and higher doses inhibit it (Oraon et al., 2021; Hussain et al., 2021; Kliszcz et al., 2023; Mozdzen et al., 2018). Similar stimulatory effects at low extract concentrations have also been reported*:* Abbas et al. (2021) observed improved maize seedling growth and pigment content with sorghum extracts, Fecowicz et al. (2020) found that aqueous extracts of dropwort roots and shoots enhanced germination indices and seedling elongation, and Gurmani et al. (2021) noted that leaf extracts of *Parthenium hysterophorus* and *Cannabis sativa* stimulated weed growth.

Collectively, these studies suggest that low allelochemical doses may promote early plant development via hormonal and metabolic regulation (Baksinskaite et al., 2023; Sharma et al., 2018; Synowiec et al., 2016).

At the seedling stage, the coleoptile length (CL) was generally less affected than root length (LR), except for the introduced genotype, which showed a marked reduction under the envelope extract treatment at 25% concentration. This pattern may be explained by the utilization of seed reserves in the tested weeds, which could differentially influence shoot and root development. Similar organ-specific responses have been reported by Noguchi et al. (1994), who observed that root growth in lettuce was more strongly inhibited than hypocotyl growth when exposed to white oat extracts. Gatti et al. (2010) attributed such differences to the distinct sensitivity of each seedling structure to the inhibitory action of allelochemicals present in the extracts, often derived from waste decomposition processes.

The grain extract significantly reduced leaf length (LL) in both wheat varieties, with inhibition intensifying at higher concentrations. This concentration-dependent effect is consistent with previous reports (Othman et al., 2018) and is likely linked to the high phenolic content of the seed extracts (e.g., syringic, ferulic, and p-coumaric acids), which can interfere with cell division, respiration, chlorophyll synthesis, and hormone balance, ultimately leading to shorter leaves and weaker seedlings (Al-Wakeel et al., 2007; Escobedo-Flores et al., 2018; Gurmani et al., 2021; Scavo et al., 2022; Bittencourt et al., 2023; Al-Qthanin et al., 2024).

Beyond individual trait responses, our findings highlight significant correlations among seedling attributes, suggesting coordinated growth strategies under allelopathic stress. A moderate positive correlation was observed between coleoptile length (CL) and root number (RN), indicating that seedlings with longer coleoptiles tend to develop more roots. In contrast, a negative correlation between root number (RN) and root length (RL) suggests a possible trade-off between root proliferation and elongation, consistent with the compensatory response described by Akter et al. (2023), whereby wheat seedlings inhibited in root elongation increase root number to sustain water and nutrient uptake. Furthermore, we found that CL and RL also varied coordinately under allelopathic stress, in agreement with previous reports showing a strong correlation between these traits (Sanad et al., 2016). This integrated growth pattern highlights their breeding relevance, as selecting for longer coleoptiles may indirectly enhance root length (Narayanan et al., 2014). Taken together, these results suggest that *Avena sterilis* allelochemicals simultaneously reshape the interdependence among seedling traits, supporting the notion of a coordinated morphological adjustment to allelopathic inhibition, as also noted by Liu et al. (2017).

Our results clearly showed that seed extracts exerted stronger inhibitory effects on root and leaf growth than husk extracts, which showed only mild inhibition. Interestingly, husk extracts even induced slight stimulation at moderate doses. This contrast indicates that allelopathic compounds are unevenly distributed across *A. sterilis* tissues, a detail often overlooked in studies that rely on whole-plant extracts. Recognizing such organ-specific variability is crucial for identifying the plant fractions that pose the highest allelopathic threat in cereal fields.

Another important finding is the stimulatory effect observed at low concentrations (25–50%), particularly in the MBB variety where maximum root number was recorded. This biphasic pattern, in which low doses of allelopathic compounds transiently promote seedling growth before becoming inhibitory at higher levels, has been previously reported (Belz, 2008; Ruan et al., 2011; Zhang et al., 2020; Li & McIntyre, 2024). By demonstrating hormetic responses in durum wheat seedlings, our study expands the scope of this concept to Mediterranean cereal–weed systems.

To further integrate and visualize the combined effects of allelopathic treatments on the different growth traits, and to better understand the multivariate relationships underlying the observed responses discussed above, a principal

component analysis (PCA) was performed. The principal component analysis further supported these findings by revealing clear group separations based on extract type, confirming that allelopathic effects are primarily driven by plant organ rather than genotype. The relatively low variance of PC1 (<50%) indicated that secondary axes also captured meaningful biological variation (Jolliffe, 2002), reflecting the multidimensional nature of wheat responses to allelopathic stress. According to Gabriel's (1971) interpretation, the variable angles in the biplot indicated correlations among traits, with RL and RN contributing most to the overall variation, suggesting that root architecture is a key determinant of allelopathic tolerance.

Moreover, the two durum wheat varieties responded differently to the extracts, with MBB showing partial tolerance to moderate allelopathic stress, unlike Waha, which was more sensitive. This highlights the role of genetic background in modulating allelopathic interactions. Such genotype-specific variability has rarely been addressed in the context of wild oat–wheat interactions, and it provides a practical perspective for selecting or breeding tolerant cultivars in fields infested with *A. sterilis*. By integrating these aspects, our study contributes novel insights into cereal–weed interactions under Mediterranean conditions.

Overall, these findings provide valuable insights for identifying allelopathic-tolerant genotypes and for developing sustainable, environmentally friendly weed management strategies in durum wheat cultivation.

Conclusions

The key findings reveal that the landrace genotype generally outperformed the introduced genotype across critical growth parameters, including RN and CL. The application of the grain extract demonstrated a significant inhibitory effect on RL and LL, with RN being positively influenced at lower concentrations. In contrast, the envelope extract showed minimal effects, with the highest LL recorded at a 25% concentration. Correlation analysis indicated a noteworthy positive relationship between CL and RN, while a significant negative correlation was observed between RN and RL, suggesting a physiological trade-off where an increase in root number may correspond to shorter root lengths.

Both genotype and concentration factors significantly influenced growth parameters, namely RL and LL. The principal component analysis (PCA) highlighted distinct patterns in variable contributions, explaining 69.99% of the total variance, indicating the importance of these parameters in differentiating the effects of the extracts.

These findings underscore the critical role of genotype selection in optimizing wheat growth under varying environmental stressors. The study suggests that the landrace genotype may possess resilience that could be leveraged to improve agricultural practices. Further exploration of these interactions could yield more effective strategies for wheat cultivation under diverse conditions. The allelopathic effect of *Avena sterilis* L. constitutes a promising area of research. An in-depth study of its allelochemical composition would allow for the refinement of agricultural strategies, optimizing its use as a cover crop, rotation crop, or hay crop. This approach could play a key role in weed suppression, thereby reducing dependence on herbicides and promoting better competitiveness of cereal crops by improving their yield and sustainability.

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