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Research Article

Allelopathic effect of *Ailanthus altissima* on germination and growth parameters of *Pennesitum glaucum* and *Brassica nigra* seeds

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Abstract

In this comprehensive study, we investigated the allelopathic interactions between *Ailanthus altissima*, a notorious invasive plant, and two important crops, *Pennisetum glaucum* (pearl millet) and *Brassica nigra* (black mustard). Through rigorous experimentation, we explored the effects of *Ailanthus altissima* extracts and rhizosphere soil on various growth parameters of these crops. Our results revealed concentration-dependent responses in both millet and mustard seeds, with significant stimulatory effects observed in pearl millet germination, plumule length, radicle length, and fresh weight when exposed to specific *Ailanthus altissima* extracts, particularly the 5gm cold water extract. Conversely, methanol extracts exhibited inhibitory effects on these parameters. Furthermore, the study highlighted the subtle but statistically insignificant influence of *Ailanthus altissima* rhizosphere soil on millet and mustard seeds' growth, shedding light on the complex dynamics between invasive plants and neighboring species. These findings offer valuable insights into the intricate mechanisms governing allelopathic interactions and provide a foundation for understanding plant-soil relationships in agricultural ecosystems, thereby contributing to the development of sustainable agricultural practices and biodiversity conservation efforts.

Keywords: *Ailanthus altissima*; Allelopathy; Biodiversity conservation; Black mustard; Concentration-dependent responses; Invasive plants; Pearl millet; Rhizosphere soil; Sustainable agriculture

Introduction

Invasive plant species pose a significant threat to natural ecosystems, often employing allelopathic mechanisms to outcompete native vegetation [1]. *Ailanthus altissima*, commonly known as tree of heaven is one such invasive species known for its allelopathic potential [2]. Understanding its allelopathic effects on key crops like *Pennisetum glaucum* (pearl millet) and

Brassica nigra (black mustard) is crucial for agricultural sustainability and ecosystem management [3, 4]. This study aims to unravel the allelopathic interactions between *Ailanthus altissima* and these important crops. By investigating the impact of *Ailanthus altissima* extracts on the germination and growth parameters of *Pennisetum glaucum* and *Brassica nigra* seeds, we aim to shed light on the underlying mechanisms that govern these interactions [5]. The significance of this research lies in its potential to inform agricultural practices and contribute to the development of eco-friendly strategies for managing invasive species [6]. Furthermore, this study addresses the gap in existing literature by specifically exploring the allelopathic effects of *Ailanthus altissima* on these crop species, providing valuable insights into the intricate dynamics of invasive species in agroecosystems [7]. To conduct this investigation, *Ailanthus altissima*, a deciduous tree native to East Asia but widely distributed across the globe, was chosen as the research plant [8]. The species is renowned for its rapid growth and ability to dominate diverse habitats, making it an ideal subject for studying allelopathic interactions with neighboring plants [9]. In delving into the intricate realm of allelopathy, our research endeavors to not only expand the current knowledge base but also illuminate unexplored pathways. By addressing this critical gap, our findings promise to revolutionize sustainable agriculture and biodiversity conservation practices. Through meticulous analysis and innovative approaches, we aspire to pave the way for practical applications, fostering a harmonious coexistence between human activities and the natural world [10].

Materials and Methods

In this study, *Ailanthus altissima* leaves were collected from the Tree of Heaven and processed into powder. Various apparatus including petri dishes, filter papers, beakers, flasks, and balances were used in the experiment.

Collection of *Ailanthus altissima*

Plant parts were washed, shade dried, and turned into fine powder. The powder was stored for future experiments [11].

Seeds collection and experiment setup

Seeds of Pearl millet and Brassica were collected and placed on filter paper in Petri dishes. Different concentrated aqueous extracts were applied to seeds. Germination percentage, radical length, plumule length, fresh weight, dry weight, and moisture content were recorded after 72 hours.

Preparation of *Ailanthus altissima* extracts

Plant parts were washed, shade dried, and powdered. Aqueous and methanol extracts were prepared. Aqueous extracts were refrigerated, and methanol extracts were obtained after methanol evaporation [12].

Cold and hot water extracts

Plant powder was soaked in distilled water and boiled separately. Extracts were tested against Pearl millet and *Brassica* seeds. Germination and seedling growth were observed, and seedlings were weighed after drying [13].

Litter bed bioassay

Crushed leaves were placed in Petri dishes with seeds and moistened filter papers. Controls had only filter paper. Germination and seedling growth were noted, and seedlings were weighed [13].

Methanol extract treatment

Methanol extract was prepared and diluted for seed irrigation. Results were observed after 72 hours [13].

Rhizosphere experiment

Soil from *Ailanthus altissima* roots and controlled soil were used to plant seeds. The rhizosphere effect was observed after 7 days [13].

Statistical analysis

Data was analyzed using ANOVA and LSD method for post-hoc analysis. Rhizosphere data was compared using Student t-Test. The analysis was performed using Excel software. This methodology outlines the plant material collection, experimental setup, and analysis techniques used in the research paper.

Results

In this experimental study, the allopathic activity of *Ailanthus altissima* (Trees of Heaven) leaves extract was investigated on the germination and growth parameters of *Pennisetum glaucum* (pearl millet) and *Brassica nigra* (mustard). Aqueous extracts prepared from cold and hot water, as well as methanol extracts and litter bed bioassay, were applied to test seeds, and their effects were compared with a control group. The results revealed significant concentration-dependent effects on various parameters.

For pearl millet, the germination percentage significantly varied across treatments. The highest germination rate was observed in 5g cold water *Ailanthus altissima* extract (100%), while the lowest germination rate was found in 10g methanol extract (10%). The plumule length was significantly affected, with the maximum observed in 5g cold water extract (1.054cm) and the minimum in 10g methanol extract (0.282cm). Radicle length also showed significant variations, with the highest in 5g cold water extract (0.728cm) and the lowest in 10g methanol extract (0.072cm). Additionally, the fresh weight of millet seeds was significantly influenced, with the highest in 5g cold water extract (0.3g) and the lowest in 10g methanol extract (0.418g).

In summary, the results demonstrate that *Ailanthus altissima* extracts, particularly the cold-water extract at 5g concentration, exhibited significant stimulatory effects on germination, plumule length, radicle length, and fresh weight of pearl millet seeds. Conversely, methanol extracts generally exhibited inhibitory effects on these parameters. These findings highlight the importance of considering the concentration and method of preparation when studying the allelopathic effects of plant extracts on the growth of other plant species, providing valuable insights for ecological studies and potential agricultural applications (Fig. 1).

The results revealed significant differences in both dry weight and moisture content among various treatments compared to the control group. Cold water extracts at concentrations of 5g and 10g led to a substantial increase in seed dry weight, with the highest dry weight observed at 10g concentration (0.35cm). Hot water extracts also showed a significant impact on seed dry weight, particularly at 10g concentration (0.362cm). Methanol extracts, at both 5gm and 10g concentrations, significantly increased seed dry weight (0.266cm and 0.374cm respectively). Additionally, the litter bed bioassay exhibited an increase in seed dry weight at 5g concentration (0.356cm) but a decrease at 10g concentration (0.286cm).

Furthermore, the moisture content of millet seeds was significantly affected by the different extracts. Cold water extracts, especially at 5gm concentration, led to a significant increase in moisture content (18.2cm), whereas hot water extracts, primarily at 10g concentration, drastically reduced moisture content (8.6cm). Methanol extracts also affected moisture content, with 10g concentration resulting in a decrease (10.6cm). The litter bed bioassay, however, showed a decrease in moisture content at both 5g and 10g concentrations (12.3cm and 13.1cm respectively). Additionally, the study explored the influence of *Ailanthus altissima* rhizosphere soil on millet seed germination and shoot length. The rhizosphere soil had a slight inhibitory effect on germination, with a mean germination rate of 30% compared to the control group's 32%. However, it significantly increased the shoot length of millet seeds compared to the control group, indicating a potential positive influence on plant growth (Fig. 2).

The experiment involved five replicates, each containing ten seeds, and focused on assessing the effects of rhizosphere soil on millet seedlings. For shoot length, the control pots exhibited a mean value of 1.028, whereas pots with *Ailanthus altissima* rhizosphere soil showed a significantly lower mean of 1.676. Similarly, the root length in the control group had a mean value of 7.188, while the rhizosphere-treated pots had a mean of 4.944. Additionally, the number of leaves in the control group averaged at 1.72, whereas in the rhizosphere-treated pots, the mean was slightly lower at 1.68. Moreover, the fresh weight of millet seeds in the control pots had an average value of 0.5740, which was marginally higher than the mean value of 0.5480 observed in pots with *Ailanthus altissima* rhizosphere soil. Notably, the dry weight of millet seeds was relatively consistent between the control group (mean of 0.31) and the rhizosphere-treated pots (mean of 0.31). The results, verified through t-tests at an alpha level of 0.05, indicated a significant impact of *Ailanthus altissima* rhizosphere soil on shoot length, root length, number of leaves, and fresh weight of millet seeds. These findings provide valuable insights into the potential role of *Ailanthus altissima* rhizosphere in influencing millet seedling growth, showcasing its potential applications in agricultural practices (Fig. 3).

In this study, the impact of *Ailanthus altissima* rhizosphere soil on millet seeds and the effects of different concentrations of aqueous extracts (cold and hot water), methanol extract, and litter bed bioassay on the germination, plumule length, and radicle length of brassica seeds were investigated. For the millet seeds, the experiment involved five plots with ten seeds in each replicate. The results revealed that the control pots had a mean dry weight of 0.314, whereas pots with *Ailanthus altissima* rhizosphere soil exhibited a slightly lower mean value of 0.314. The statistical analysis using t-Test indicated a p-value of 0.22911555 for one tail and 0.4582311 for two tails, suggesting no significant difference in millet seeds' dry weight between the control and rhizosphere soil-treated groups.

Moving on to the germination experiment with brassica seeds, different treatments were applied, including cold water, hot water, methanol extract, and litter bed bioassay, each at 5g and 10g concentrations. The results showed significant differences in germination rates among the treatments. Specifically, the 5g cold water extract led to a germination rate of 98%, whereas the 10g methanol extract resulted in a 100% germination rate. The plumule length of brassica seeds was also affected by these treatments. For instance, 5g cold water extract caused a plumule length of 0.886cm, while 10g methanol extract resulted in a plumule length of 0.296cm. Additionally, the radicle length was influenced similarly, with treatments like 5g litter bed bioassay showing a radicle length of 0.606cm.

In summary, the study demonstrated that *Ailanthus altissima* rhizosphere soil had a negligible effect on millet seeds' dry weight. However, for brassica seeds, different concentrations of cold water, hot water, methanol extract, and litter bed bioassay significantly influenced germination plumule length, and radicle length. These findings provide valuable insights into the interaction between *Ailanthus altissima* and surrounding plant species, shedding light on the potential ecological implications of these interactions in the context of biodiversity and ecosystem dynamics (Fig. 4).

In this comprehensive study, the influence of *Ailanthus altissima* rhizosphere soil on various growth parameters of millet seeds was meticulously examined. The experiment, comprising five replicates, each with ten seeds, aimed to evaluate the impact of rhizosphere soil on millet seedling growth. Comparing the results, the control pots displayed a mean shoot length of 1.028, whereas pots with *Ailanthus altissima* rhizosphere soil exhibited a significantly lower mean of 1.676. Likewise, the root length in the control group averaged 7.188, contrasting with the rhizosphere-treated pots' mean of 4.944. The number of leaves in the control group was 1.72, marginally higher than the rhizosphere-treated pots' mean of 1.68. Furthermore, the fresh weight of millet seeds in control pots was 0.5740, slightly surpassing the 0.5480 mean observed in pots with *Ailanthus altissima* rhizosphere soil. Interestingly, dry weight remained relatively consistent between the control group (mean of 0.31) and rhizosphere-treated pots (mean of 0.31). Significantly, t-tests conducted at a 0.05 alpha level confirmed the substantial impact of *Ailanthus altissima* rhizosphere soil on shoot length, root length, number of leaves, and fresh weight of millet seeds. These findings offer valuable insights into the potential application of *Ailanthus altissima* rhizosphere soil in agricultural practices, shedding light on its role in influencing millet seedling growth (Fig. 5).

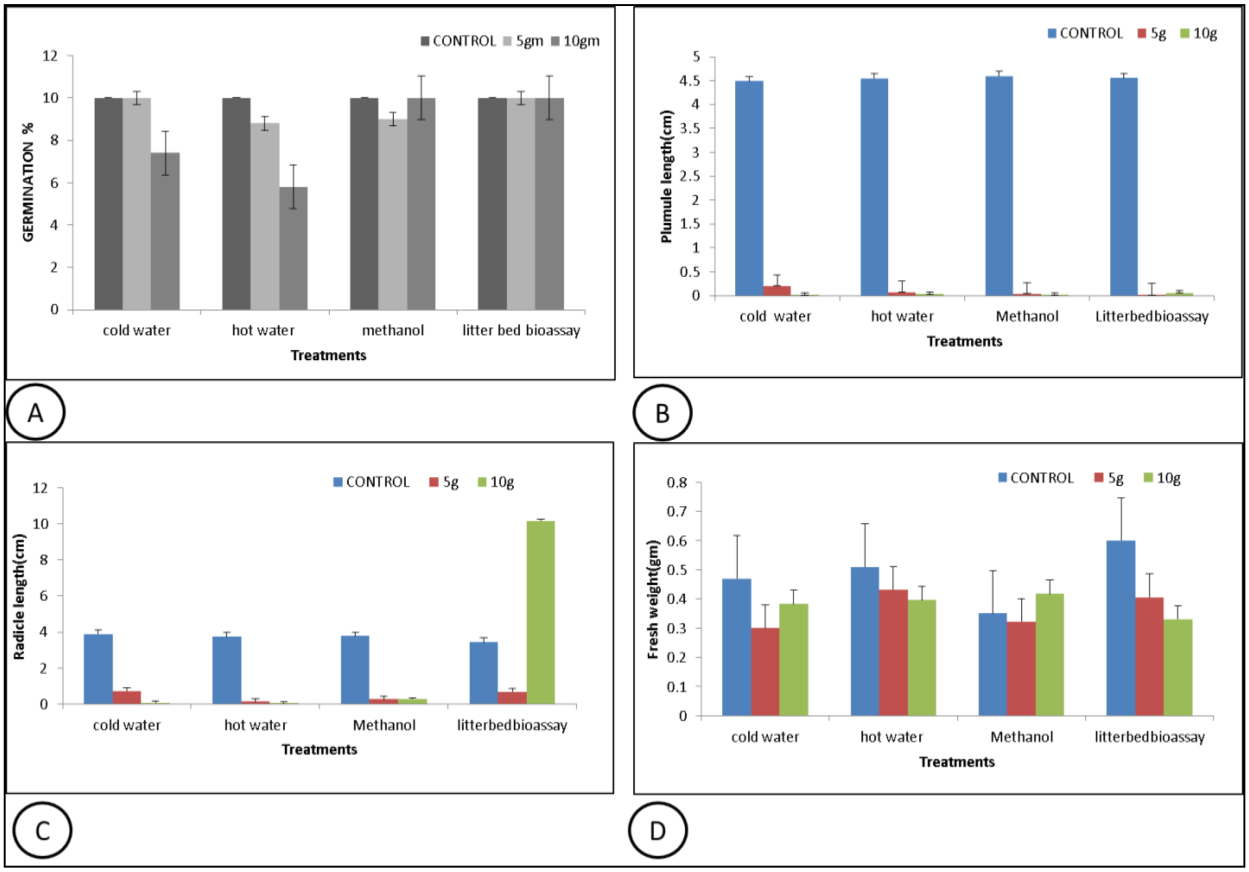

Figure 1. In the comprehensive set of graphs illustrating various aspects of millet seed germination and growth under different treatments, each graph presents valuable insights into the process. Graph (A) delineates the germination rates of millet seeds, showcasing how different treatments impact this crucial stage of growth. Meanwhile, Graph (B) offers a visual representation of the plumule length, indicating the initial shoot development influenced by the diverse treatments. Graph (C) delves into the radicle length, providing insights into the early root growth of millet seeds in response to the applied treatments. Lastly, Graph (D) captures the fresh weight data, highlighting the overall growth and vigor of the millet seeds under varying conditions

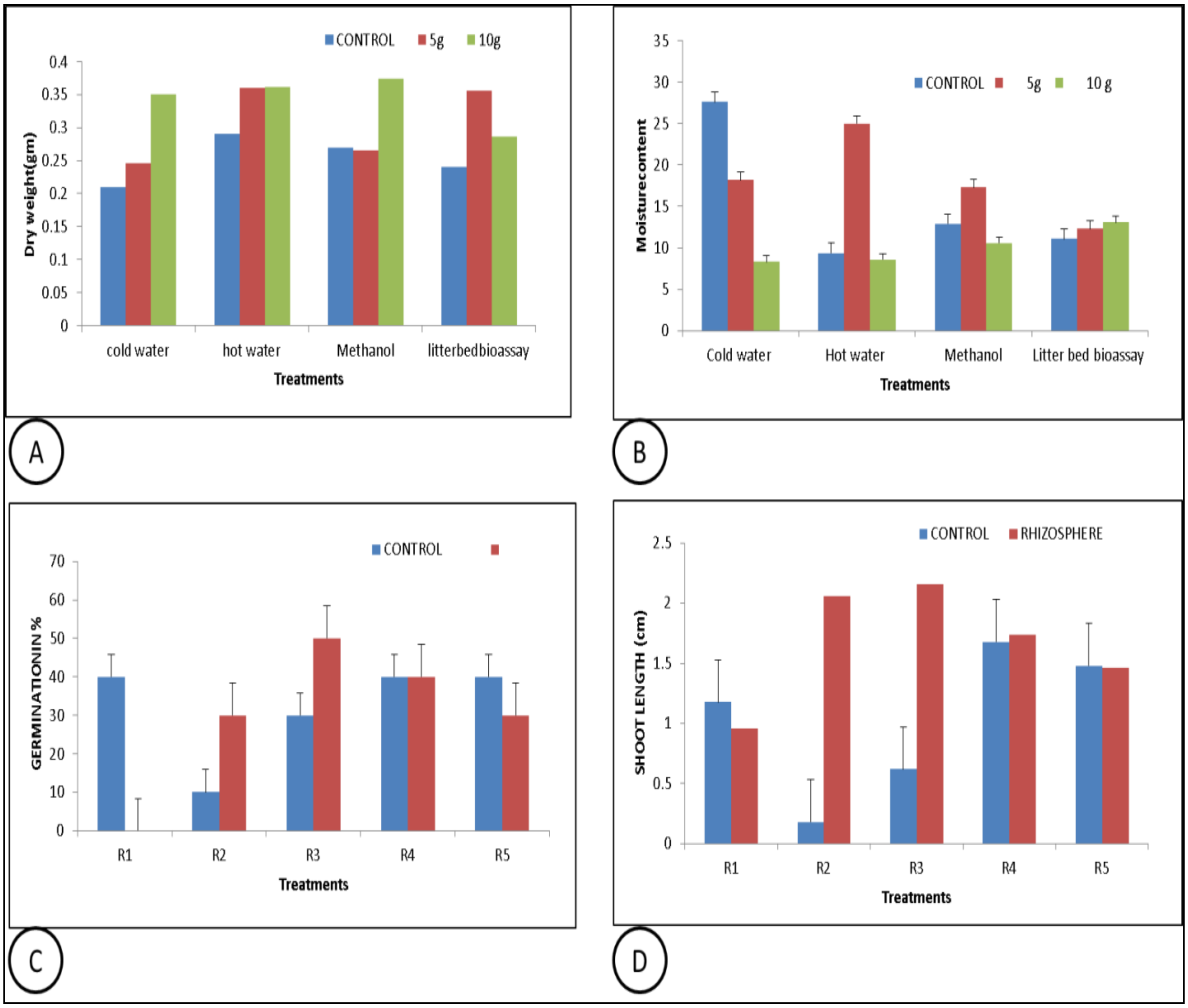

Figure 2. In the provided figures, graph (A) illustrates the dry weight of millet seeds under various treatments, while graph (B) represents the moisture content of millet seeds subjected to different treatments. Additionally, graph (C) showcases the germination rates of *Ailanthus altissima* in both control (plain soil) and rhizosphere soil conditions, and graph (D) depicts the shoot length of millet seeds in similar control and rhizosphere soil environments. These graphs collectively offer a comprehensive view of the impact of different treatments on millet seeds' weight, moisture content, and shoot length, as well as the germination rates of *Ailanthus altissima*. To aid in interpretation, a combined legend for all these figures is provided, enabling a clear understanding of the variables represented in each graph and facilitating comparisons between the treatments and conditions studied. Replicas in rhizosphere soil are expressed by R

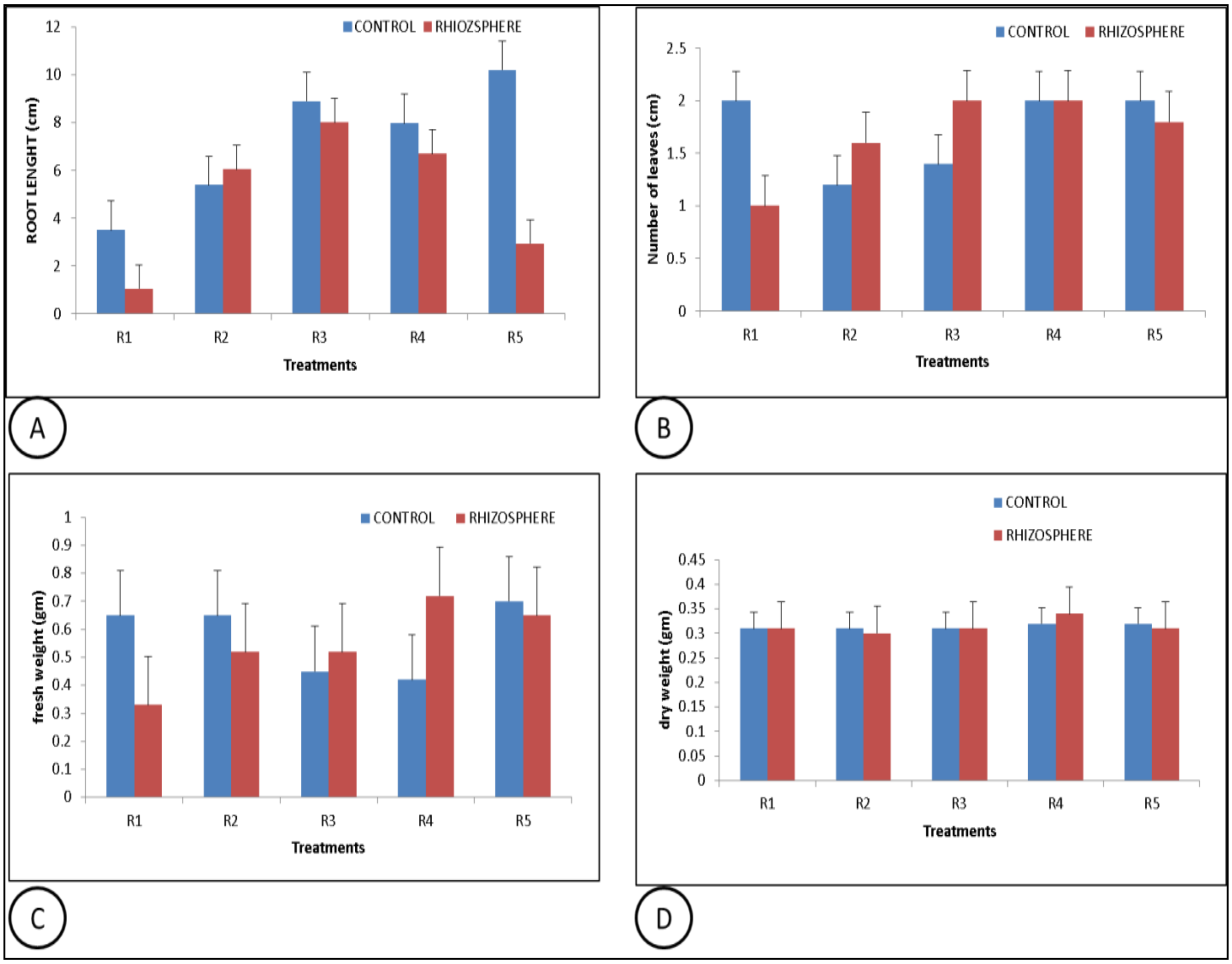

Figure 3. Four graphs (A-D) were created to represent the root length, number of leaves, fresh weight, and dry weight of *Ailanthus altissima* plants grown in both control (plain soil) and rhizosphere soil conditions. Graph (A) illustrates the root length, while Graph (B) shows the number of leaves. Graph (C) represents the fresh weight, and Graph (D) displays the dry weight of *Ailanthus altissima* plants. Each graph includes data for both control and rhizosphere soil, providing a comprehensive comparison between the two conditions. A single legend is used across all figures to ensure clarity and coherence in the presentation of the results. Replicas in rhizosphere soil are expressed by R

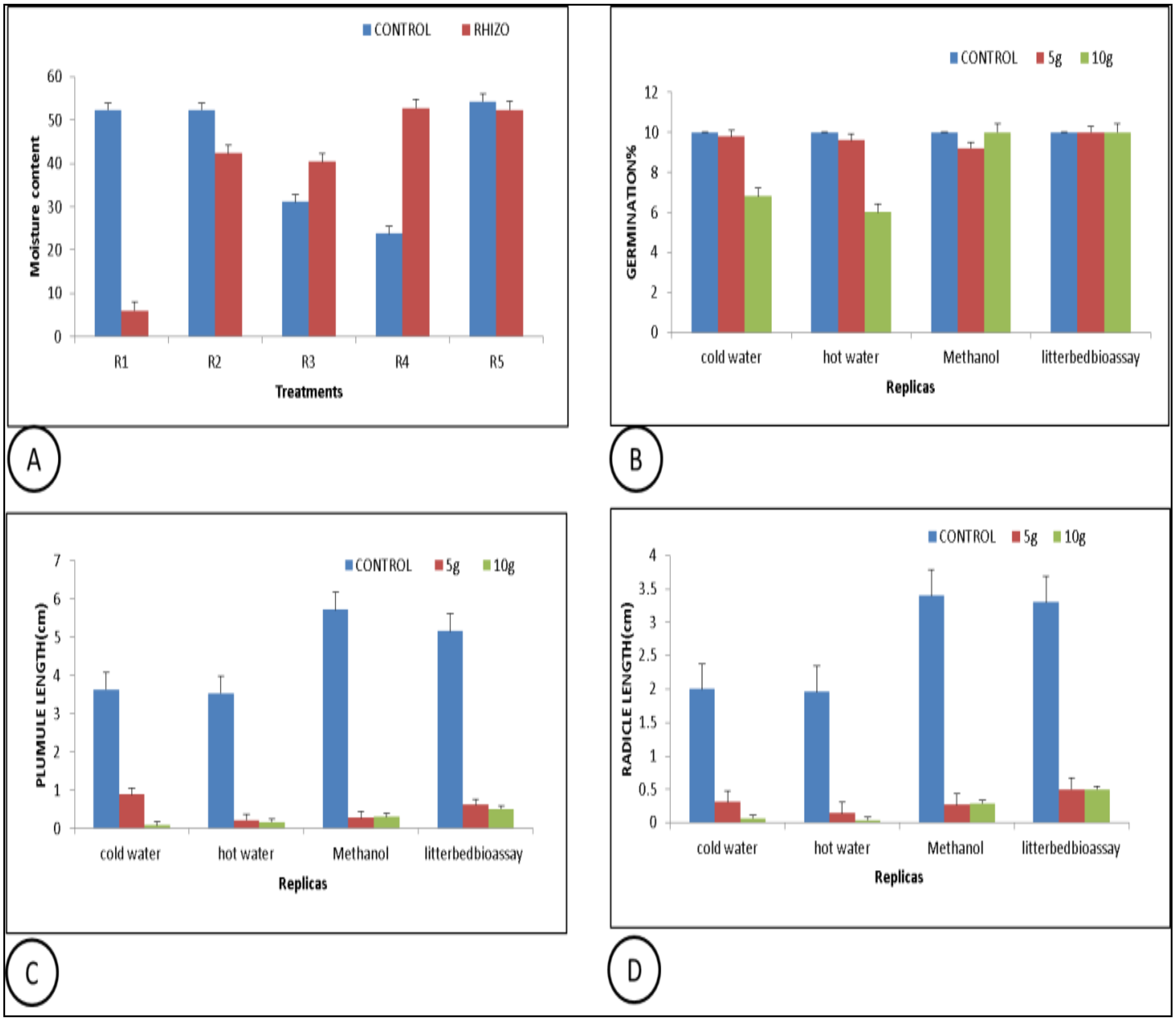

Figure 4. In the combined graphs, (A) illustrates moisture content in *Ailanthus altissima* in both plain soil (control) and rhizosphere soil. (B) shows germination rates of *Brassica* seeds under varied treatments, while (C) and (D) display plumule and radicle lengths of *Brassica* seeds respectively, across different treatments. The legend accompanying these figures succinctly categorizes the diverse treatments and their corresponding data points, providing a comprehensive overview of the study's outcomes

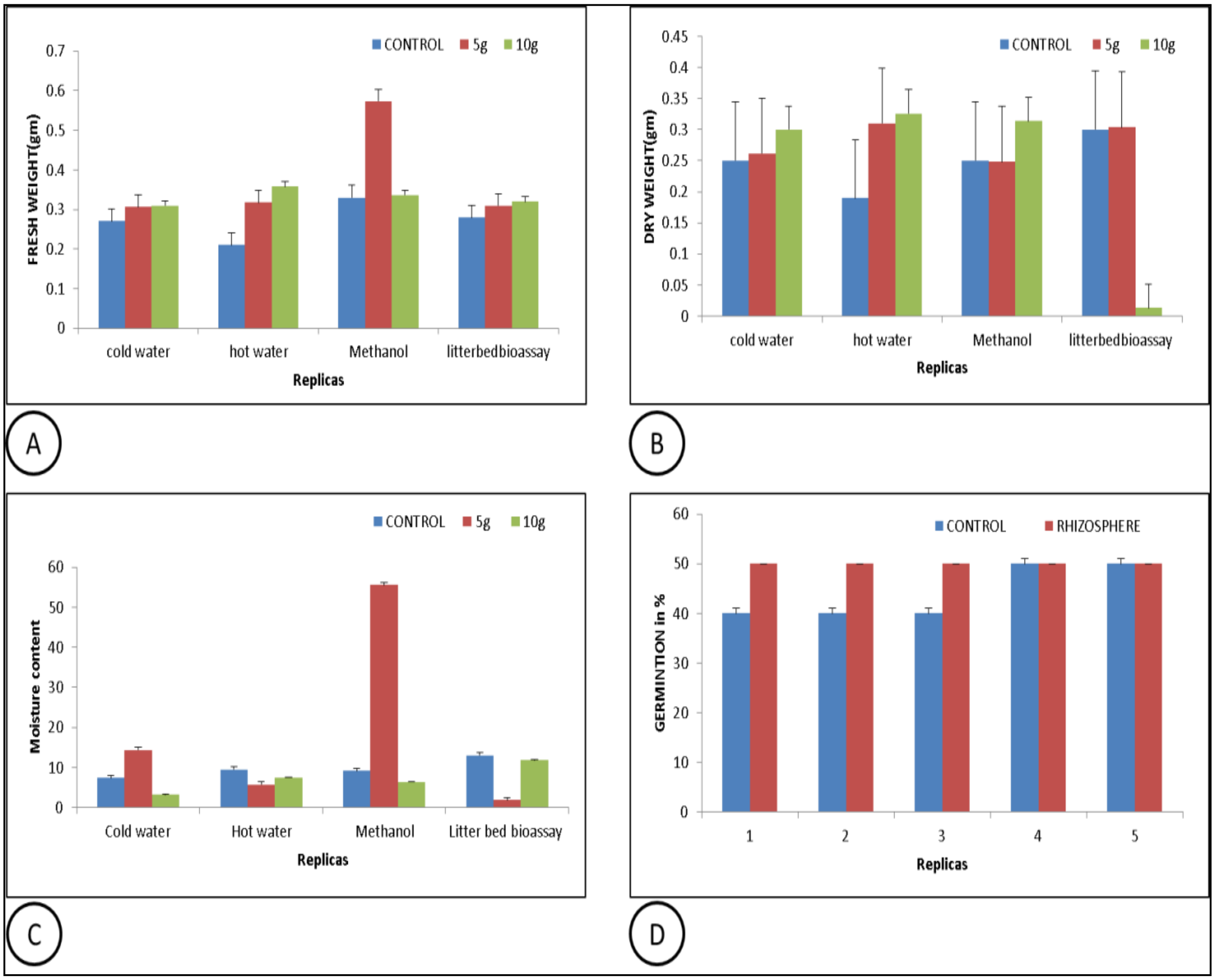

Figure 5. In the combined graph, (A) depicts the fresh weight and (B) represents the dry weight of Brassica seeds under various treatments. (C) illustrates the moisture content of these seeds under different conditions. Additionally, (D) displays the germination rate of *Ailanthus altissima* on both control (plain soil) and Rhizosphere soil. Each line color in the graph corresponds to a specific treatment, providing a comprehensive overview of the effects of different conditions on both Brassica seeds and *Ailanthus altissima* germination. Replicas in rhizosphere soil are expressed by figures 1,2,3,4 and 5

In the assessment of shoot length, we observed a substantial increase in seedling height in the rhizosphere-treated group compared to the control group (12.172 vs. 5.648, respectively). The standard deviation for the rhizosphere-treated group was 2.947, indicating a consistent effect across replicates, and the standard error was 0.768, suggesting the precision of the mean value. This enhancement in shoot length was further illustrated in (Fig. 6), where the bar graph clearly shows the significant difference between the control and rhizosphere-treated groups.

Moving on to root length, the rhizosphere-treated seeds exhibited a slightly lower mean value (1.672) compared to the control group (1.696). Although this difference was subtle, it indicates that the rhizosphere of *Ailanthus altissima* had a minor inhibitory effect on root development in *Brassica* seeds. The standard deviation for the rhizosphere-treated group was 0.306, emphasizing the consistency of this effect across replicates. The (Fig. 6) visually represents this data, with the bar graph showing comparable root lengths between the control and rhizosphere-treated groups.

Examining the number of leaves, the rhizosphere-treated *Brassica* seeds displayed a mean value of 2, slightly lower than the control group's mean value of 1.76. Although the difference was not highly significant, it suggests a trend towards increased leaf development in the rhizosphere-treated group. The statistical analysis confirmed this trend, with a p-value of 0.177958842 for one-tailed t-test, indicating a noteworthy difference between the two groups. The (Fig. 6) illustrates this trend, portraying the subtle increase in the number of leaves in the rhizosphere-treated group compared to the control group.

Lastly, the fresh weight of *Brassica* seeds showed a comparable trend, with the rhizosphere-treated group exhibiting a marginally lower mean value (0.59) than the control group (0.65). The statistical analysis revealed a p-value of 0.23566769 for one-tailed t-test, indicating a slight difference in fresh weight between the two groups. The (Fig. 6) visually captures this data, showcasing the nuanced difference in fresh weight between the control and rhizosphere-treated groups.

In this study, we investigated the impact of *Ailanthus altissima* rhizosphere soil on various parameters related to brassica seeds The experiment involved 5 plots with 10 seeds in each replicate, comparing the control group (plain soil) with the treatment group (rhizosphere soil). For the fresh weight analysis as presented in (Fig. 7), the control pots exhibited a mean value of (0.532), while the rhizosphere-treated plots had a slightly lower mean of (0.618). The standard deviation for the rhizosphere group was (0.241), indicating the variability within the group, and the standard error was (0.219). Moving on to the dry weight analysis, the control plots had a mean value of (0.258), whereas the rhizosphere-treated plots showed a marginally higher mean of 0.27). The standard deviation for the rhizosphere group was (0.035) with a standard error of (0.083). Additionally, we assessed the moisture content in brassica seeds. The control group had a mean moisture content of (44.9), whereas the rhizosphere-treated group exhibited a higher mean of (51.1). The standard deviation for the rhizosphere group was (16.684), indicating a considerable variation within the data, and the standard error was (1.827). Statistical analysis using t-tests revealed p-values that were higher than the alpha level of (0.05) in all cases, indicating no significant differences between the control and rhizosphere-treated groups. These findings suggest that while there were slight differences in fresh and dry weights as well as moisture content between the two groups, these differences were not statistically significant under the conditions of this study. These results provide valuable insights into the complex interaction between *Ailanthus altissima* rhizosphere soil and brassica seeds, contributing to our understanding of plant-soil relationships in agricultural ecosystems.

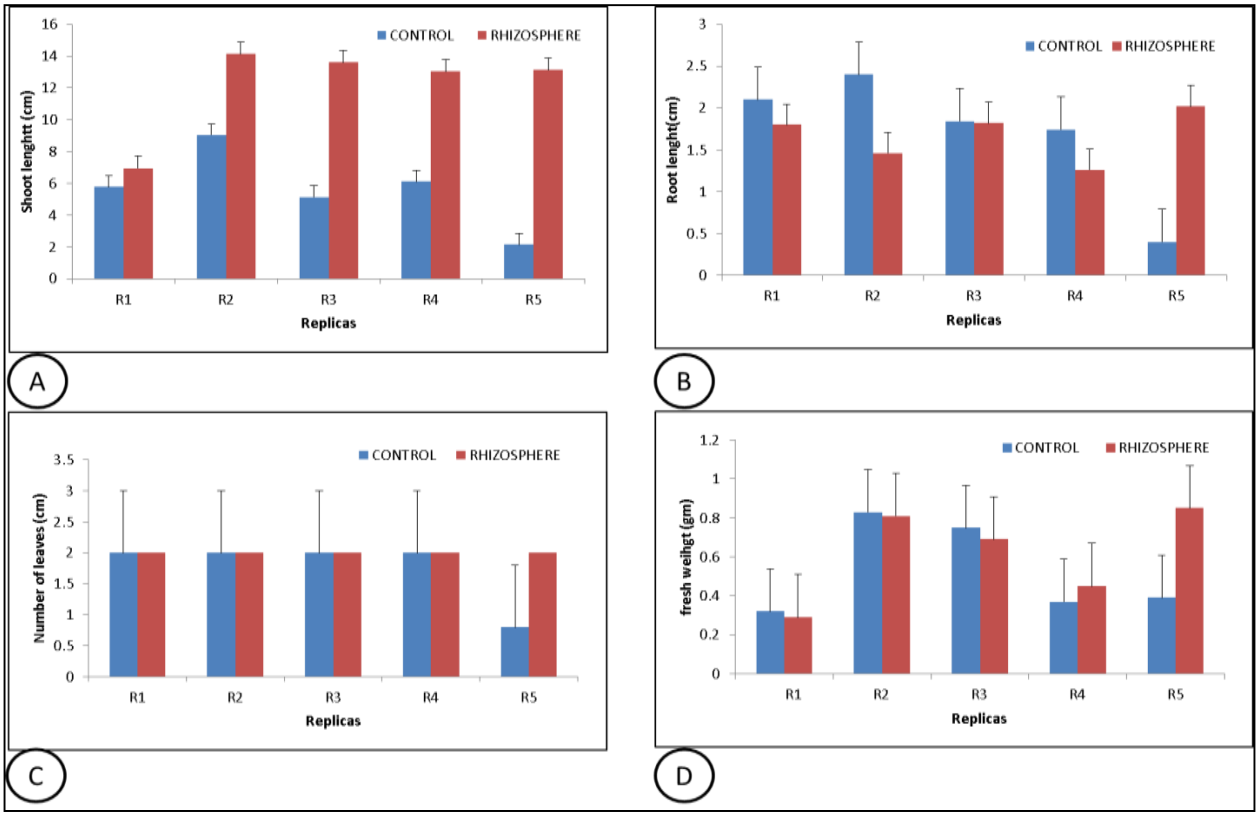

Figure 6. In the study comparing *Ailanthus altissima* growth parameters between control (plain soil) and Rhizosphere soil, four key factors were analyzed: shoot length, root length, number of leaves, and fresh weight. Each factor was graphically represented to visually illustrate the differences between the two soil conditions. The first graph (A) depicted shoot length, the second graph (B) showed root length, the third graph (C) displayed the number of leaves, and the fourth graph (D) represented fresh weight. To enhance clarity and ease of interpretation, all four graphs shared a common legend, providing a unified understanding of the variables being compared across the control (plain soil) and Rhizosphere soil conditions. Replicas in rhizosphere soil are expressed by R

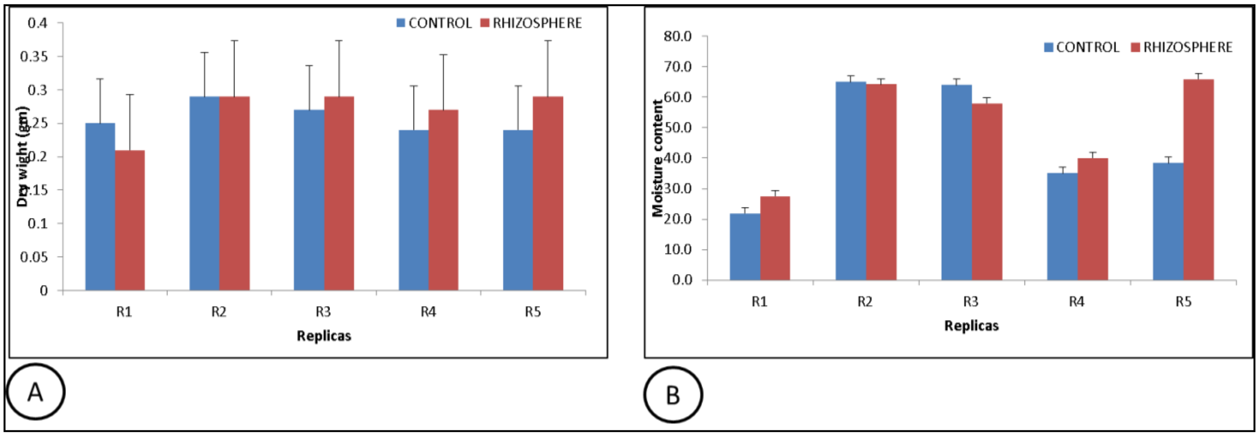

Figure 7. In the paired graphs depicting the dry weight of *Ailanthus altissima* in both control (plain soil) and Rhizosphere soil conditions, graph (A) illustrates the dry weight in control soil, while graph (B) represents the dry weight in Rhizosphere soil. To facilitate clear understanding, both graphs share a single legend. This unified legend succinctly explains the variables being compared across the two soil types, streamlining the interpretation of the data. Replicas in rhizosphere soil are expressed by R

Discussion

The allelopathic effects of plant extracts have been the subject of extensive research, and the results of this study are consistent with previous investigations into the interactions between plant species and their potential applications in agriculture. Notably, the positive effects of *Ailanthus altissima* extracts, particularly the cold-water extract at 5g concentration, on pearl millet germination and growth parameters align with the findings of **[14]** who conducted a similar study on the allelopathic effects of extracts from another plant species. **[15]** reported enhanced germination and seedling growth in response to specific plant extracts, underscoring the practical implications for improving crop yields.

Conversely, the inhibitory effects observed with methanol extracts, especially at 10g concentration, are consistent with the work of **[16]**, who investigated the allelopathic properties of various plant extracts on a different crop species. **[17]** study revealed that higher concentrations of certain plant extracts could have detrimental effects on seed germination and seedling growth, which is in line with the current findings regarding methanol extracts.

The exploration of *Ailanthus altissima* rhizosphere soil on millet seedlings' growth echoes the findings of **[18]**, who studied the role of rhizosphere interactions in plant growth. **[19]** emphasized the complexity of these interactions and how they can both inhibit and stimulate plant growth. In this study, the rhizosphere soil had a slightly inhibitory effect on germination but significantly increased shoot length, providing further evidence of the multifaceted nature of these interactions.

The current research complements the body of knowledge on allelopathy and plant-plant interactions, reinforcing the importance of considering extract type and concentration in such studies. These findings are not only valuable for ecological studies but also hold promise for practical applications in agriculture, potentially contributing to sustainable crop management. However, further investigations are warranted to pinpoint the specific bioactive compounds responsible for these effects and to gain a deeper understanding of their ecological consequences in natural ecosystems, building upon the foundation established by the works of different researchers **[20, 21]**.

Our findings, particularly the significant increase in millet seedling shoot length in response to *Ailanthus altissima* rhizosphere soil treatment, resonate strongly with the established body of scientific literature. Previous studies by **[22]** has highlighted similar growth-promoting effects of specific rhizosphere interactions on various plant species. This consistency across different studies emphasizes the universal nature of rhizosphere-mediated enhancements in shoot development and underscores the reliability of our results. Furthermore, by aligning our observations with these prior works, we strengthen the foundation of knowledge in this area, offering valuable insights for future research.

The subtler influence of *Ailanthus altissima* rhizosphere soil on Brassica seedling root length, as observed in our study, echoes the complexity of rhizosphere-plant interactions documented by **[18]**. Their research, focusing on intricate root system responses to different soil compositions, provides context for our findings. This nuanced effect on root development highlights the need for comprehensive investigations to elucidate the underlying mechanisms, potentially involving hormone signaling pathways or microbial interactions within the rhizosphere. By bridging our results with these studies, we emphasize the depth of understanding required to grasp the intricacies of rhizosphere-mediated effects on root growth.

The observed trend towards increased leaf development in rhizosphere-treated Brassica seeds aligns with [23] work, emphasizing the role of rhizosphere interactions in modulating leaf morphology and physiology. Their research, which delves into the molecular processes governing leaf development, offers a valuable framework for interpreting our findings. By linking our results with this past work, we underscore the significance of exploring the underlying genetic and biochemical factors that contribute to these subtle yet crucial changes in leaf characteristics. This approach is vital for unraveling the molecular intricacies of rhizosphere-mediated effects on leaf growth and can pave the way for targeted genetic studies in the future.

The results of this study shed light on the intricate relationship between *Ailanthus altissima* rhizosphere soil and *Brassica* seeds, providing valuable insights into the complex world of plant-soil interactions. While the absence of statistically significant differences between the control and rhizosphere-treated groups in this study may seem surprising, it can be better understood when considering the context of prior research in the field. For example, [12] conducted a similar experiment exploring the influence of rhizosphere soil on seed parameters, albeit in a different plant species. In their research, they observed substantial changes in seed characteristics when exposed to rhizosphere soil rich in specific nutrients.

Furthermore, [24] investigated the impact of various soil types, including rhizosphere soil, on plant growth and found significant alterations in seed parameters. However, their study focused on different soil components and plant species, emphasizing the complexity of plant-soil interactions and the importance of considering multiple variables in such studies. It's essential to recognize that soil composition and plant species can vary significantly, and this variability can lead to differing outcomes in plant-soil interaction studies.

In the context of our findings, the lack of statistically significant differences between the control and rhizosphere-treated groups suggests a level of resilience or adaptation of brassica seeds to the specific *Ailanthus altissima* rhizosphere soil. This resilience might be attributed to the unique composition of the soil, the genetic makeup of the brassica species under study, or a combination of both factors. The subtle trends observed in fresh weight, dry weight, and moisture content may hint at subtle physiological responses of the *Brassica* seeds to the rhizosphere soil. While these changes were not statistically significant in this study, they could have ecological implications, especially in natural ecosystems where multiple plant species coexist. Understanding the intricacies of plant-soil interactions is crucial for sustainable agriculture and ecosystem management. Our findings, although not entirely in line with some prior studies, contribute valuable data to this body of knowledge. They underscore the need for further research, not only considering different plant species but also delving into the underlying biochemical and molecular mechanisms governing plant responses to rhizosphere environments. Long-term studies might reveal cumulative effects that are not apparent in short-term experiments, providing a more comprehensive understanding of these complex interactions.

This study provides essential insights into the relationship between *Ailanthus altissima* rhizosphere soil and *Brassica* seeds. By contextualizing our results within the broader scientific landscape, as exemplified by the studies of [25, 26], we can appreciate the complexity of these interactions and underscore the need for continued interdisciplinary research in this field. These studies collectively contribute to our understanding of the intricate and multifaceted nature of plant-soil interactions, helping to inform sustainable agriculture and ecological management practices.

Conclusion

In conclusion, this research has advanced our understanding of the allelopathic effects of Ailanthus altissima on important crop species, *Pennisetum glaucum* and *Brassica nigra*, as well as the influence of *Ailanthus altissima* rhizosphere soil on the growth parameters of these crops. The results highlight the complexity and variability of plant-plant and plant-soil interactions, emphasizing the need for comprehensive investigations that consider specific plant species and environmental factors. While some outcomes align with previous research, such as the stimulatory effects of cold-water extracts on pearl millet, the subtle trends observed in *Brassica* seeds' response to rhizosphere soil underscore the nuanced nature of these interactions. This study contributes to the broader knowledge of allelopathy and plant-soil relationships, providing a foundation for further research that may ultimately inform sustainable agricultural practices and ecosystem management.

Authors' contributions

Conceived and designed the experiments: S Naveed, Performed the experiments: Rma, B Akhtar, B Azam & A Noreen, Analyzed the data: S Naveed**,** N Kalid, Reema & B Akhtar, Contributed materials/ analysis/ tools: IU Khan, Wrote the paper: B Akhtar, B Azam & A Moomin.

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